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**WBS 4.1.2.2**  
**Pathfinder Technologies Specialist, X-37**  
**Final Report**

**Milestone Deliverable**  
**Contract NAS8-99060**

**September 30, 2001**

**Prepared for**

**Space Transportation Directorate**  
**George C. Marshall Space Flight Center**  
**National Aeronautics and Space Administration**

**Prepared by**

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## **WBS 4.1.2.2**

# **Pathfinder Technologies Specialist, X-37**

# **Final Report**

### **Background**

The X-37 vehicle is a technology demonstrator sponsored by NASA. It includes a number of experiments both imbedded (i.e., essential aspects of the vehicle) and separate. The technologies demonstrated will be useful in future operational versions as well as having broad applications to other programs. In the longer view, X-37 is intended to demonstrate the capability of an orbiting vehicle with substantial propulsion capability to perform missions both for NASA and USAF. X-37 will be placed in orbit by some launch vehicle (some candidate vehicles require expenditure of some X-37 propellant) and will use the majority of its onboard propellant for orbital operations. The Space Shuttle is the chosen launcher for the first two missions. This will deliver X-37 to orbit with a full propellant load. The X-37 is a winged vehicle with a "butterfly" tail. As far back as the wing trailing edges, the planform is similar to the Space Shuttle Orbiter but the fuselage extends further aft and mounts the two ruddervators that are the tail surfaces. This configuration is more stable at high angle of attack than delta configurations such as Shuttle or X-33. These latter vehicles tend to run away in pitch above a certain high angle of attack, meaning a risk of flipping over. In the X-37 configuration, the tail surfaces come out of the wing shadow as angle of attack increases resulting in a pitch down tendency.

### **Task Results**

Mr. James R. French, of JRF Engineering Services and as a consultant to SAIC, has provided technical support to the X-37 NASA Program Office since the beginning of the program. In providing this service, Mr. French has maintained close contact with the Boeing Seal Beach and Rocketdyne technical teams via telephone, e-mail, and periodic visits. His interfaces were primarily with the working engineers in order to provide NASA sponsors with a different view than that achieved through management channels.

Mr. French's periodic and highly detailed technical reports were submitted to NASA and SAIC on a weekly/monthly basis. These reports addressed a wide spectrum of programmatic and technical interests related to the X-37 Program including vehicle design, flight sciences, propulsion, thermal protection, Guidance Navigation & Control (GN&C), structures, and operations. During Option Year 1 (10/1/99 – 9/30/00), of Contract NAS8-99060, Mr. French's reports were provided directly to sponsoring and management personnel at NASA and SAIC. A summary of the Option Year 1 periodic reports was provided to NASA as a milestone deliverable, "Pathfinder Technologies, X-37" dated September 30, 2000.

This subject milestone deliverable on WBS 4.1.2.2 is entitled "Pathfinder Technologies Specialist, X-37" and is dated September 30, 2001. It is presented in the following pages as a consolidation of the twelve monthly reports submitted by Mr. French during Option Year 2 (10/1/00 – 9/30/01) of the contract. This report is submitted as an adjunct to the above-mentioned summary report for Option Year 1 and, as such, constitutes the final report for WBS 4.1.2.2 of Contract NAS8-99060.

## **JRF ENGINEERING SERVICES**

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31 October 2000

**To:** Edgar W. Nicks  
**From:** Jim French  
**Subject:** X-37 Monthly Report

C: S. Turner, Lt. Col. Johannessen, M. Harris, J. London, B. Armstrong, S. Stewart, Maj. Titus

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### **X-40A**

#### **Program Comment**

It is difficult not to notice the high incidence of wiring damage plaguing the X-40A (see G,N,&C below. It is possible of course to shrug this off as resulting from coincidence however, that strains credulity to a degree. If the problem is systematic, it is difficult, from this perspective, to say whether the cause is poor manufacturing and/or QA practice or careless or inept work on the vehicle. If the various cables come from different sources, that tends to reduce the probability that it is the manufacturing process and focus attention on the work at DFRC. The delays from these sources are costing precious time and putting the program at risk of greater delay. It might be worthwhile to apply some attention to this concern.

#### **Flight Test**

The condition of the lakebed continues to be an issue. Lakebed runway 25 was badly rutted and torn up by C-17 tests. The Flight Test Center repaired the runway to the point that they considered it suitable for the large aircraft that they normally operate. There was concern that it might not be acceptable for X-40A with its small wheels and relatively high speeds.

Some consideration was given to defining a surrogate "virtual runway" in the guidance system. This would be physically located just north of and parallel to runway 25. Since

the X-40A has no depth perception problems, the lack of markings was not an issue and the lakebed in that area looked fine. The rains eliminated that option.

I have been concerned for sometime about an early onset of the California winter rains; we are moving into the southern California rainy season. The first rain occurred on 10 October. As a result, the lakebed became temporarily unusable. If there is no more rain for a while, the lakebed will probably dry sufficiently for at least limited use. Exactly when it will be fully usable again is TBD. As soon as it rains enough to accumulate water on the lakebed, runway 25 will be out of action since it is at the low end of the lake. This could happen any time. The other lakebed runways will be available for a while after the rains start (probably) but eventually they too may be out of action. If we have a flight or two under our belt when the lake becomes unusable, we may be able to talk the base commander into allowing X-40A to use the paved runway. However, the probability of being allowed to use it for the first landing is effectively zero. Thus, it is important to move out smartly to get the first drop behind us.

If we lose use of the lakebed, White Sands Space Harbor may be an option but it would require considerable effort to relocate the flights.

It is not clear exactly when the helicopter will be back because of various conflicts and the need to get the proper blessings from DFRC concerning the computer and other issues.

Training having been completed for the first free taxi tests, the free flight training is in progress.

Taxi testing has progressed well. Towed runs were made building speed up to 45 mph. When these went well, the team proceeded to free taxi tests. One release was conducted at 17 mph followed by four more at 27 mph. The Flight Computer worked well. There were no uncommanded reboots nor did the computer hang up or lose telemetry. The tests went well insofar as procedures and test equipment were concerned.

Some new issues did arise however (see G,N,&C below).

### **Vehicle Systems**

The Flight Computer was tested by exposing it to an artificially created high rate interrupts to verify that this causes a reboot. This test was done prior to the low speed taxi tests. All this was done in concert with the software supplier, Wind River. Provision will be made for storing data in the event a reboot does occur. The core memory will be dumped following every normal run to verify no high rate interrupts. Methods of protection are being evaluated.

Software will be modified to deal with the Ethernet problem.

Moog has indicated that actuator life expectancy is not a problem. Boeing and government personnel will want to review the results before a final determination is made but it sounds promising.. This covers not only flight operations but the required testing between flights. These tests are required to verify actuator condition prior to the next flight.

Moog also identified a possible problem with regenerative power from the actuators. In order to control the regenerative power, a 10,000 microfarad capacitor and a resistor will be added to the power lines leading to the actuators to dissipate the generated energy.

Rewiring of vehicle circuits is in progress. The major efforts are the VRS repair, addition of filters to the string potentiometer circuits, and replacement of the J-2 connector. These changes have been discussed previously in connection with the anomalies encountered in flight. The work also includes the actuator circuit changes discussed above.

The cables between the Flight Computer and C-MIGITS were inspected and tested by flexing and twisting the cables to determine if any more shorts or other problems exist. Upon conclusion of the rewiring, a series of checkouts will be run prior to resuming taxi tests.

The test team continues to request a higher transmit power for Command and DGPS. The request is somewhere in the DFRC approval cycle.

### G,N,&C

On initial turnon for the taxi tests, the C-MIGITS did not see satellites and there was no DGPS. However during a one-hour hold for another program, it began to see satellites and by the time testing was resumed, DGPS was working. The C-MIGITS was found to exhibit a 1 Hz oscillation in pitch and yaw. The amplitude was about  $\pm 0.1$  degree. Since the nosewheel steering uses yaw data from C-MIGITS, corresponding oscillations were seen in the nosewheel steering commands and position feedback. Finally it was noted that, during the test, the vehicle missed some uplink commands issued by the FOCC and it was further noted that there was a delay between when a command was issued and when it actually left the FOCC. These issues are being investigated. The EDU is in the vehicle for testing at the moment and the team began looking for a flight-worthy loaner in case the problem with the flight unit can't be fixed or takes too long to fix. A possible candidate loaner was identified.

The DGPS receiver is at the manufacturer for repair of a problem with the squelch circuit.

A representative from Radstone, the Flight Computer manufacturer, came to DFRC to work on the computer problems. First was the reset problem. This had occurred three times, once on the captive flight and twice in ground test. A second problem was the computer suspending operations. It does this very repeatably in response to certain

conditions. Finally, he inspected the damage to the J2 connector discovered during investigation in connection with the original reset problem.

It has been discovered that an excessive number of interrupts from C-MIGITS can cause the Flight Computer to reset. It is not known whether this caused the problem encountered in the captive flight but it is certainly a strong possibility (see below). Unfortunately the flight telemetry does not report C-MIGITS interrupts so there is no way to prove or disprove the speculation. The phenomenon was discovered in ground test where such data are recorded.

In connection with the above, investigation of the C-MIGITS problem resulted in discovery of an intermittent short circuit in the cable connecting C-MIGITS to the Flight Computer. The short tends to put noise on the line which looks very much like interrupts to the computer. While we cannot know with absolute certainty that this has been the source of the reset problems, the probability seems very high. The Radstone rep apparently feels that this is the case.

The Radstone rep has also worked with the team in making some changes to eliminate the hangup problem. With these changes made and the short repaired, the Flight Computer has been running very well. At his suggestion, the J-2 connector with the damaged faceplate will be changed. That is a very straightforward operation of moving pins from one backshell to another. It is not even necessary to remove the cable from the box. It appears that we can be cautiously optimistic that the computer problem is fixed.

The C-MIGITS used in the tests reported above was the unit borrowed from Long Beach. As part of the investigation of the 1Hz oscillation, previous data were reviewed and it was found that the EDU C-MIGITS had a similar oscillation but at 6 Hz rather than 1 Hz. The manufacturer confirmed that this oscillation is not normal and wanted the unit back for repair. A software problem might have been fixed in a few days. A hardware repair however was estimated to be a month or more. The flight C-MIGITS is already in the shop for repair and may be as much as a month away from being returned.

The possibility exists of obtaining an immediately available, new, C-MIGITS unit. The cost is about \$21,000.

After reviewing the various options discussed above, the decision was made to repair the existing C-MIGITS. The problem turned out to be a broken coax antenna lead. Repair and checkout are stated to require two weeks.

## X-37

### Program

Analysis of loads into X-37 from the B-52 is being conducted. The loads will then be applied to the vehicle "Build To Packages" to determine if the designs are adequate. The results of this may affect structures and other components. Since hardware is already being fabricated and purchased, results could have significant impact. The problem is that having hardware built tends to ratchet the weight up. If hardware is already built and loads analysis shows that it can be lighter, it is unlikely that the part will be scrapped and a new lighter one built. On the other hand, if the analysis shows that the part needs more strength, something will probably be "scabbed on", almost certainly heavier than a part optimally designed for the loads in the first place.

Boeing is working both Shuttle and B-52 loads issues very hard and hope to come to closure on this topic within a few weeks. They feel that their analysis is converging to a solution. Dryden loads experts are working with their Boeing counterparts.

The acoustic environment on the pylon remains a major uncertainty. It seriously impacts the engine and the entire aft end of the vehicle. DFRC has provided only very rudimentary data to Boeing regarding acoustics. They claim to have no detailed model of the acoustics. I find this astonishing considering the variety of vehicles that have flown on this B-52 over some 40 years beginning with X-15. Numbers like 150 dB are bandied about for antennas on the vehicle. This is huge amount of energy. It is 20 to 30 dB above the spec for the SRAM missile, which flies on a nearly identical pylon position. A very large number of thin-skinned aluminum vehicles have flown on that pylon (M2-F2, HL-10, X-38, etc.) and I don't think they could have tolerated such an environment. Something does not make sense and I find it hard to understand why DFRC is not able to provide better information. (Bear in mind of course, that I am reporting the Boeing side of the story.) In any case, Boeing has obtained X-38 acoustic data from JSC and is using that for design. That should be conservative since X-38 is a bigger, wider vehicle and parts of it will be much closer to the B-52 nacelle.

Generally speaking, it appears that the loads issues are being worked and that cooperation between DFRC and Boeing is fairly good at the working level. Unfortunately, the analysis is coming to closure later than would have been desired, resulting in possible weight and/or redesign problems as noted above. The one exception is the acoustic environment, which, for whatever reason, remains fuzzy. Other than keeping an eye on the situation, I do not believe any specific action is required by the NASA P.O. although helping to unravel the acoustic confusion would certainly be a benefit.



## **Vehicle Design**

The vehicle weight is at about 6439 lb., about 60 lb. over target weight. The growth curve continues to flatten out but still has not turned downward. Thus weight is still "holding", i.e. climbing only slowly. However there is great concern that there are many unknowns that may still cause a large increase. Fabricating hardware while still doing loads analysis carries this risk with it.

## **Propulsion**

Rocketdyne is having cash flow problems and may have difficulty continuing through the end of CY2000. The tentative plan is to work only on the Qualification engine for the rest of the year and put off work on the Flight engine until later. This would apparently solve the cash flow problem now. The downside, predictably, is increased overall program cost resulting from building engines sequentially rather than in parallel.

Rocketdyne is looking at the costs of doing vibration tests on the engine to support Shuttle integration. They had not originally planned to do any such testing. This was probably a case of excessive optimism.

The zero-g tests have been completed. There was some difficulty in getting the information because of the NASA data recording approach. At this point it is not known whether the propellant level sensors worked or not. XXXXX

The propulsion review with the Shuttle safety board generally went quite well. The upshot is that the board feels that, with oxidizer system as designed, they are not unduly concerned with the hydrogen peroxide. It turns out, however, to the surprise of many, that they are more concerned about fuel. A little additional oxygen, even if hot, does not worry them so long as there is no damaging plume impingement. A fuel spill however could result in a serious fire. Boeing is looking at the issue.

Despite the concerns regarding the B-52 inputs to the engine, Rocketdyne is not currently working on the analysis of this issue. They are not funded for this task and currently are making a proposal to Seal Beach for funding to support the analysis.

Rocketdyne is considering two approaches to resolving the issue of the B-52 loads. One option is to build up a test engine out of non-flight parts and subject it to vibration and acoustic tests, which would envelope the expected flight environment. The other approach is to build a more detailed computer model of the structure and attempt to qualify it by analysis. It is not clear which option is the lowest cost. Rocketdyne is running a cost analysis. Vibration facilities are available at low cost however it would be necessary to build a test fixture and a second gimbal block and gimbal interface bracket. The gimbal hardware is probably more expensive than the fixture.

Rocketdyne intends to have an agreed upon plan for the qualification issue by the end of October.

One positive aspect of the testing option is that it would qualify the gimbal block. As noted previously, the original block had huge margins but Rocketdyne changed the materials to reduce weight. Now, no one is really sure what the margins are. Although there are plenty of assurances that we have lots of margin, the case for testing the block is much stronger than it would have been with the original.

Rocketdyne is working on the Action Items from the recent internal and external design reviews. Naturally there is some overlap and repetition. Most of the items from the internal review have been dealt with. They are working with Reggie Alexander on a closure schedule for the items from the external review.

To address the concern over a possible fuel spill in the payload bay (see last week's report), Rocketdyne is adding two additional relief valves so as to provide a double inhibit between the fuel and the payload bay. This adds weight but appears to be unavoidable.

An additional complication with the gimbal block design used on the X-37 is that it is so designed that the tightness of the assembly bolts defines the load on the gimbal joint. The Shuttle lateral load environment may demand tightening up the bolts, conceivably to the point that the actuators may have trouble moving the engine. In the original application of the gimbal block, this was not a problem because it was always vertical and the engine was firing at liftoff. Here, the engine is off and the loads are lateral as well as axial. It is probable that the Shuttle nose gear slap-down loads are the driving case.

It turns out that there is another piece of hardware that must be fabricated: the oxidizer pump inducer. One exists but another is needed. The question then arises, is it better to make two so that what is tested in the qual engine is the same as flight. There is a tendency to say "Why bother" if the new one is made of the same material, to the same print. However, the answer was not that easy. The shape is a complex compound curve defined by certain specific points. The fabrication technique is quite different with modern machines. Thus while the defined points may be identical in both cases, the exact shape between them might vary. There was concern that such subtle differences can have impact upon performance, natural frequency, cavitation, etc. After due consideration, however, Rocketdyne has opted to build just one. The current thinking is that the differences would be too small to matter, especially given the low head rise of the inducer.

When considering testing of a structural test model engine to resolve the issue of the ability of the engine to withstand B-52 and Shuttle loads, the question arises as to the test level. Clearly the test levels must envelope the worst case flight environment. The question is, by how much margin. In spacecraft testing, a structural test unit and/or a qual unit might be run at 6dB above expected flight while a flight unit might see 3 dB over. The question is, do we want to go this high on a test article engine. Rocketdyne is uncertain as to the answer. While the answer will depend to some degree upon further analysis of loads and capability, I am against pushing to high levels. We have precious

little hardware. We need to qualify it but not to break it in an effort to hit arbitrarily defined levels. This needs some discussion.

### **Flight Sciences**

Calibration of the model RCS thrusters is complete at LaRC. The RCS model is back at AEDC for installation. Testing should begin soon. CFD analysis is in progress to provide a comparison with the test data.

The tunnel work at NASA Ames will probably be less fruitful than was hoped. They are having difficulty hitting the planned Reynolds number points. Whether this results from problems with the tunnel or inexperience of the operators is not clear.

### **Structure**

Much of the concern regarding the loads on the ruddervators stems from the fact that Boeing originally planned on deflecting the surfaces 5 degrees while on the B-52 as part of the checkout procedure. They designed the load capability for 10 degrees deflection to provide margin. Initially DFRC said this was okay. Now however, DFRC's position is that they must deal with a full 40 degree deflection. At the originally planned airspeed of 300 keas the loads at full deflection were totally unacceptable. As a result airspeed was reduced to 260 keas. Loads are acceptable at this speed with no gusts. However the defined 37 ft/sec gust would fail the structure. The compromise is that, in the event of a hardover failure, the B-52 will immediately slow to 230 keas, at which speed the loads are tolerable even with the worst case gust. This compromise is based upon the fact that a 37 ft/sec gust is unlikely at best and is very unlikely during the brief period of deceleration.

Analysis is going on in this area. It may still be necessary to beef up the fuselage at the points where the ruddervator loads are absorbed. As noted below, it is too late to do anything about the sill longeron but other elements can be strengthened, if needed, to accept the loads.

The door sill longeron tooling is complete. While this is good news in one sense, it means that the longeron configuration is fixed and that no weight reduction can be had if loads turn out to be lower than the design values.

The installation of the X-37 in the Shuttle is complex in terms of structural analysis. The X-37 is supported on two pallets, each of which are independently attached to the Shuttle payload interfaces. The aft structure of X-37 is bolted to a plate attached to the aft pallet. The plate is parallel to the Shuttle aft bulkhead (horizontal in launch position). At the front end, two trunnion pins on the X-37 rest in trunnion mounts on the forward pallet. One can easily see that there are many degrees of freedom and that it is not determinant

structure. Initial analysis tried to make do with a simple static model but this did not give realistic results. This in turn forced use of a complex dynamic model to determine the loads. The results of the more complex analysis may impact the design.

Substantial weight was saved in the Shuttle interface areas, both forward and aft, by some fairly detailed analysis. This has helped stem the weight growth

## **Operations**

The combined team is evaluating X-37 electrical requirements on the B-52 to determine what if any changes will be required at the B-52 interface.

Range Safety reiterates that , under the current scheme, if the vehicle TM downlink is lost, the vehicle will be terminated no matter how well it was flying prior to the loss.

Initial antenna pattern testing on the X-37 configuration has been completed.

Several issues have come up regarding FTS batteries. In one case, Boeing wants to fly Li-ion batteries because of weight and temperature range tolerance. However, such batteries have not been used in this application previously and are not considered properly qualified by Range Safety. Needless to say Range Safety is very conservative about new hardware. Ni-Cd and Ag-Zn batteries are qualified and acceptable to the range but are too heavy and lack the temperature tolerance that Boeing feels they need. In order to use Li-ion batteries in this application, an extensive qualification program would be required.

The required operating lifetime of the batteries is driven by requirements to operate through descent, entry and landing, i.e. from deorbit burn through wheel stop, plus all on-orbit checkout. Range safety insists, reasonably enough, that the final on-orbit checkout also be done on the actual FTS battery. In addition there are earlier checkouts. This could translate to the FTS being on the battery for one to three orbits prior to the deorbit burn. This becomes a significant number of watt-hours and drives battery size. A possibility is to "diode or" the vehicle power into the FTS circuit so that preliminary checks could be done on vehicle power before switching to the FTS battery for the final check. If there will be some significant time between the final check and the deorbit burn, it may be possible to switch back to vehicle power until just before the burn. Once the burn starts however, the FTS battery is to be locked in as the only power source. This approach may satisfy the range while cutting down FTS battery weight.

A B-52 interface meeting was held between Boeing and DFRC and seemed to go very well. Most of the issues appear to be ironed out and Boeing feels ready to move forward with the design effort.

The acoustic environment data on the B-52 that was originally presented to Boeing is generally held to be high by an order of magnitude. This, if true, should greatly reduce the concern about acoustically driven loads.

It appears that approval will be granted to use the Ensign Bickford laser firing units of FTS.

DFRC is urging the use of a C-band beacon. They admit that such a beacon is not mandatory but express the opinion that not having it substantially increases the risk to the vehicle and the mission since, if TM is interrupted, Range Safety will destroy the vehicle no matter how well it seems to be flying.

All B-52 interface work and analysis to date has been based upon the B-52B (the currently used aircraft). When the planned B-52H conversion becomes available, it is hoped that the change will be essentially transparent to the user. There are some differences however. The mount on the H sits farther forward than it does on the B. As a result, there may be less separation down force when dropping from the H because the X-37 will be more exposed to the upwash at the wing leading edge than it is when mounted on the B. It is reported that the X-15, a longer vehicle that protruded farther forward, experienced less downforce than stubbier vehicles.

The acoustic environment on the H should be much better, both because of the forward location and the quieter turbofan engines.

A possible disadvantage of the H is that it apparently will not have the wing structural enhancement that is incorporated in the B. This limits the weight of the drop vehicle. It is not clear whether this will be a problem for X-37. When the H becomes available (target January 2002), the B may be placed in flyable storage unless specific users are identified.

The B-52 is unable to accurately simulate the entry vehicle conditions at the drop altitude. Paradoxically, it apparently cannot fly slowly enough at 40 to 45 Kft. altitude to simulate the speed of the X-37. This is probably a manifestation of the very high drag of the X-37. The B-52 must maintain 0.75 to 0.8 Mach at these altitudes. Current drop condition will be 43,000 ft (about 40,000 agl) at 200 keas, which is about Mach 0.79

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30 November 2000

**To:** Edgar W. Nicks  
**From:** Jim French  
**Subject:** X-37 Monthly Report –November

C: S. Turner, Lt. Col. Johannessen, M. Harris, J. London, B. Armstrong, S. Stewart, Maj. Titus

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### **X-40A**

#### **Flight Test**

Another rain on 29 October left standing water on the lakebed, precluding operations early in the week. However, by Friday, 3 November, it was dry enough for additional taxi testing. These final low speed taxi tests were generally very successful. The maximum speed obtained was 42 mph. Some minor uplink problems were encountered but these are generally considered to be caused by obstructions. High speed testing was scheduled to begin the week of 5 November.

The Air Force Flight Test Center (AFFTC) approved the higher broadcast power for Command and DGPS requested for the vehicle (see last month), however, they did not approve the requested increase in bandwidth. The logic for this is not obvious since the total bandwidth requested lies well within the allocation for DFRC. Boeing views this as simply more obstructionism. DFRC seems unwilling to push on the FTC on this matter and became very irate when Boeing personnel proposed to go directly to the FTC. The political environment seems to get progressively worse.

Because of concern about the rain on the lakebed, discussions were initiated with Range Safety and the AFFTC regarding landing on the hard surface runways. While the answer was not the flat "No" that I expected, a number of problems were raised, not the least of which was schedule. Various USAF programs are having to work six or seven days per week to get main runway time. Because of this X-40A will not be able to schedule the runway ahead of time during the week. Scheduling ahead on weekends might be easier.

This really seems like a show-stopper. We could hardly sit around for days with the X-40A loaded on the B-52 just in case somebody cancels. The possibility of using lakebed Rwy 22 was also broached. This might be possible if 25 were unusable. If 25 can be used, 22 will probably not be approved. In order to enhance probability of flight, we need to be able to land on any runway and to fly on short notice. The practicality of this is TBD. It has been concluded that using the Main Base runway (paved) has an acceptable  $E_c$  on weekends however such use has yet to be approved at the top levels.

Some of the lakebed runway is still soft and has sinkholes caused by the rain. Work is in progress on the runways. More length is needed for the high speed work.

Boeing wants to get two flights in before the end of the CY. The schedule to do this is very tight already. The helicopter and crew are at EAFB. A number of tests are required before flight and, of course, Mother Nature needs to cooperate by providing dry weather. The helicopter crew is under orders to head for home no later than 21 December.

Investigation of the anomaly that involved blowing the parachute piston out of the vehicle indicates that excess flow through the DFRC-mandated second solenoid was the problem. For off-vehicle testing, flow was reduced by plugging one of the three orifices. Testing was done with both solenoids and 3000 psi supply pressure and one solenoid at 1800 psi. Both were successful.

After permanent modifications are made, three more tests will be conducted on the vehicle to verify the modifications. However, at month's end, these tests have not yet been conducted. The possibility of letting the sabot depart the vehicle is being considered. Boeing wants to fix the problem but apparently there is some dissension surrounding the issue.

### **Vehicle Systems**

After some delays caused by hardware problems, validation of the build 7.1 software began on 10/31.

The capacitor for the regenerative power protection modification has been received and installed.

Following the parachute tests noted above, the orifices will be modified to give equivalent flow, with all three open, to that obtained in the tests with one plugged.

### **G.N.&C**

The C-MIGITS was brought up from Anaheim late on 10/31

## **X-37**

### **Program**

The forthcoming discussions of program modifications will be interesting. I think that there might be ways to obtain much of the desired data without building a second airframe or risking our only X-37 airframe. Basically this involves use of the X-40A as the atmospheric test vehicle and dropping it from the Scaled Composite Proteus aircraft. Proteus was investigated early in the program but rejected because it could not carry X-37 without significant modifications. It could, however, carry X-40A. In fact it could launch higher and faster than the B-52. Scaled had no particular issue with dropping a single-string controlled vehicle. The X-40A carries the CADS so testing with it would give experience with that system. The planform and aerodynamics of the X-40A are somewhat different from X-37 with the latest changes to the latter but since an extensive wind-tunnel data base exists for both vehicles, correlation of results should not be difficult. I believe that this option is worth considering as compared to building a second X-37 air frame.

It seems likely that very little will be done before the week of 4 December because of activity on the NRA 8-30 proposal. To meet the due date, that proposal will have to be through the writing stage by the end of that week. Activity on the X-37 should pick up at that point.

I have done some preliminary looking into their requirements and compliance matrix, via telephone. The summary is that, in the beginning, they never really had such a thing. There was pressure from within and without Boeing that they really needed some formalism in this area. As a result, they are now working on back-filling this particular lack. I have an appointment to go over all this with ray Bartlett during my visit 6 and 7 December.

### **Vehicle Design**

The vehicle weight is still slightly above 6400 lb. This number includes the 500 lb payload weight. The lower limit of the zone in which the vehicle will have to be placarded for sink rate and possibly other parameters begins at 6400 lb and extends to the maximum weight of 6800 lb.

The current weight is probably tolerable but there are several potential increases looming that considerably exceed any anticipated reductions. Thus the weight is almost certain to increase by a significant amount.



Some of the weight growth comes about from actual data being received on the actuators. They are heavier than planned. This is aggravated by the decision to have actuator commonality to save cost. This means that some actuators are heavier than an optimum design would be. Because most actuators are aft, ballast is necessary to control CM, further aggravating the weight situation. Another source of weight growth is the problem with the lower fuselage skins described later.

The acoustic loads still appear to be too severe even using the X-38 data. The solution to this issue is not clear.

A question has arisen over whether the X-37 needs to be Fail Operational / Fail Operational / Fail Operational / Fail Safe or just Fail Operational / Fail Operational / Fail Safe. The consensus seems to be that it is the latter requirement that is appropriate for this vehicle.

### **Propulsion**

Rocketdyne is fabricating hardware and preparing to assemble the Qualification engine. Money is tight but Rocketdyne management feels that they can meet the schedule.

Most other activity is on hold while decisions are awaited on various proposals, e.g. the Brassboard. Most Seal Beach personnel are working on the NRA8-31 proposal.

### **Flight Sciences**

The wind tunnel work is going very well for the most part and is nearing completion. Low speed testing is essentially done as is much of the medium speed work.

In the high-speed regime, the first set of Mach 10 data were obtained when the heaters failed in the tunnel. Repair is expected to take considerable time, therefore the model is being removed and mounted in the Mach 6 facility.

With the completion of medium speed tests at AEDC, that model is headed for Ames Research Center. Tests will begin there in January.

The RCS tests in Tunnel A and Tunnel B are done and work in Tunnel C will begin shortly. Preliminary looks at the data are very promising and seem to correlate well with the CFD. There is no indication of serious coupling problems such as plagued X-33.

If all continues to go well, all but two sets of wind tunnel work will be complete by the end of December. Because the engineers are wrapped up in the testing, there has been very little analysis of the data but quick look analysis looks good.

The Flight Sciences lead will be pressing to add a small set of tests at high altitude, say 270,000 ft. there has been little attention paid to that regime and it would be good to have some data to anchor CFD.

### **Structure**

A serious problem has arisen in fabrication of the lower fuselage skin. When the skin was pulled from the mold, it was noted that, because of core condensation at the lower corners, the vertical walls leaned inboard. Springing these vertical walls out to the proper position overstressed the skin in the corners. Two fixes are identified. Both involve cutting out the core and inner skin in the corners. In one case, the remaining core would be panned down and several layers of cloth added to make the corners into a single thick skin section rather than a honeycomb structure. In the other case, separate parallel rows of honeycomb, probably three, would be laid in the cutout and new skin added on the inside. The former fix is favored.

Also a triangular area high on the port side just forward of the wing cutout experienced core collapse. The offending core and inner skin will be cut out and replaced.

There will be a weight penalty of perhaps 15 lb for these repairs. The irony is that, if heavier core had been used, the condensation and collapse probably would not have occurred. Heavier core was planned originally but was replaced with lighter material to save weight. This repair probably more than eats up the original gain. This is not particularly a matter for recrimination. The program is pushing as hard as it can to reduce weight. It is to be expected that, once in a while, they will overshoot.

It will be necessary to beef up the fuselage structure that takes the ruddervator loads in order to meet DFRC's requirements for a 1.25 factor of safety on a hardover surface at 260 keas. More weight.

The change request to beef up the ruddervator attach structure has been submitted but has not been approved. These changes are required to withstand loads caused by hardover deflection on the B-52

### **Operations**

DFRC has not backed off on the very high B-52 acoustic inputs originally given to Boeing. Boeing is continuing to work using X-38 data. There may be some risk that this will become an issue later.

Boeing has been planning to test each control surface actuator individually just before drop and then to leave the actuator powered but commanded to neutral position while

others are tested. When all are tested, X-37 will be ready to drop. DFRC is saying that each actuator should be tested individually and then turned off. The X-37 would be dropped with actuators unpowered. They would be powered up a few seconds after release.

This seems ridiculous. Turning the actuators off partially invalidates the checkout just completed. Further, as discussed in earlier reports, it may not be safe for X-37 to drop without controls active because of the effects of B-52 airflow.

The procedures and documentation for the Shuttle interface will require major manpower. Boeing may not be able to do it alone. They may require help.

NASA MSFC and DFRC are cooperating on a paper that will strongly recommend inclusion of a C-band beacon in X-37. Boeing feels that it is unnecessary because the worst case situation shows VAFB picking up telemetry a safe distance off-shore. However, the safety people are strongly in favor of including the beacon.

The requirement for a 72-hour on-orbit checkout prior to re-entry still stands but a great deal of clarification is needed.

I have reviewed the first draft of the KSC Ground Operations Plan and provided comments to Boeing.

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30 December 2000

**To:** Edgar W. Nicks  
**From:** Jim French  
**Subject:** X-37 Monthly Report – 30 December 2000

C: S. Turner, Lt. Col. Johannessen, M. Harris, J. London, B. Armstrong, S. Stewart, Maj. Titus

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### **X-40A**

#### **Flight Test**

Taxi tests have reached 60 mph. Some anomalies have occurred with C-MIGITS and RAJPO involving resets of the microtracker during the taxi tests. This is being investigated and is tentatively attributed to battery problems in the device.

The first captive flight test was scheduled for 8 December pending approval by the MSFC Center Director. The approval was received and the test was successfully conducted as scheduled. Several runs were made including climbs and descents to calibrate the radar altimeter. The only serious problem noted to date was dropouts in the C-MIGITS data. It is not known if the problem is with C-MIGITS or with the ground station. In either event, it is potentially a major problem since loss of data during free-flight could result in Range Safety aborting the mission.

Except for the C-MIGITS problem, the captive flight went very well, validating procedures and giving the crews valuable experience. Some adjustments in the sling will be required to get the proper angle on the X-40A but that should be minor.

The helicopter crew is being sent home for the holidays. The C-MIGITS data dropouts experienced on the captive flight must be corrected prior to further flights. So far, no clear explanation has emerged and it seemed foolish to keep the crew sitting around when the probability of another flight before the Christmas shutdown was becoming

increasingly remote. Therefore, the earliest possible date for the next captive flight will be early January.

Work continued, during the month, on repair of lakebed runway 25.

It was reported earlier that the test team was investigating an anomaly that involved blowing the parachute sabot out of the vehicle, apparently because of excess flow through the DFRC-mandated second solenoid. It was reported to me and hence in these reports that, in off-vehicle testing of a configuration where flow was reduced by plugging one of the three orifices, two tests, done with both solenoids and 3000 psi supply pressure and one solenoid at 1800 psi. were successful. It turns out that they were successful in the sense that the FTS worked and the parachute came out. However, the sabot ejected as well.

Evidently, the problem is that, when the 'chute ejected, the sabot was stopped by its restraint cable as planned. However, over the next second or so the pressure behind the drive piston, continuing to build up, blows the sabot out. By this time the 'chute is probably fully deployed and the sabot may punch a hole in it.

The easiest solution seemed to be to eliminate the sabot restraint cable so that the sabot exits the X-37 with the 'chute and will fall away before the 'chute fills. However there was also a push, apparently mostly from Boeing, to "Fix it right" so the system operates as originally designed. The system was finally modified so that the sabot was restrained; see Vehicle Systems below.

The good news is that the FTS works fine and the 'chute has never failed to eject properly.

### **Vehicle Systems**

The parachute canister back plate was routed out to make room for the larger snubber required to hold the sabot in the vehicle. The machining made a portion of the plate too thin so that a strengthening plate was bolted to the back plate to strengthen it. This plate interfered with structure around the canister requiring further modifications. However, the system was ultimately tested and appeared to be fully successful. This should clear one obstacle from the path of free flight.

The C-MIGITS dropout problem is being closely investigated. It is not yet clear if it is a C-MIGITS problem or a communications issue.

## X-37

### Program

Boeing is working to develop a system that shows requirements and their derivation as well as the approach to compliance. The system was briefed to the NASA Program Manager on 6 December. The approach seems promising but rather elaborate. It will be interesting to see how well it works in practice. As noted earlier, the Boeing project really had no system for keeping track of these things until this task began recently.

### Vehicle Design

As predicted in earlier reports, the weight increased by about 190 lbs. to 6621. This is only 179 lbs. below the limit. Possible increases are identified as 158 to 203 lbs. and possible decreases now are about 152 lbs. These numbers change daily.

The latest increase came from a number of sources. The actual actuator weights are 94 lbs above the estimates. The lower fuselage skin repair is coming in at about 27 lbs. An increase in battery capacity from 30 to 43 watts-hour will cost about 30 lbs. The remainder of the increase is from a variety of small items.

The above does not include the cabling issue discussed below.

There is some possible relief from the actuator weights. Moog makes several different motor sizes, gear box sizes and jack screw sizes, which they can mix and match rather easily. At the moment, all actuators are the same with size driven by the largest requirement. Given the variety of hardware available, it is not clear that cost of customizing the actuators for each application would be prohibitive. The numbers of items are not so big that there is any great advantage in quantity buying of all one size (at last in the opinion of some Boeing personnel). Also, all actuators have dual motor coils. This may not be required in every case, affording further opportunity for reduction.

### Propulsion

The NASA Propulsion FDR team has expressed concern regarding the small amount of hard data in the Propulsion Splinter package. I still do not have EVS access however, I reviewed the document while I was at Boeing this week. RIDs and comments were submitted to the Propulsion FDR leader. My comments follow:

- As suggested in verbal discussions, the package was somewhat disappointing in the lack of quantitative data. The package is a good status report but without much supportive detail.
- I find no major fault with the fuel tank except that the fabrication procedure is very labor intensive. It probably does not matter greatly for making a single unit, but it certainly does not take advantage of the producibility of composite structures.
- Details on fabrication of the oxidizer tank are scarce. I infer that it is made in two halves and girth welded. There is little information about the material characteristics, loads, weld verification, etc.
- On page 20 under "Propellant Management" there is mention of a "bubble position wicking vanes". Wicking implies a large surface area. If this is true, it will tend to promote decomposition of hydrogen peroxide.
- There is some inconsistency in the propellant dump procedures. No pressure level is specified for Depletion Dump Concept #1. Whereas, pressure settings P-5 and P-6 are quoted for Depletion Dump Concept #2.
- In Depletion Dump Concept #1, is the pressure pulsing process controlled by the flight computer?
- I have some concern about the emergency deorbit and propellant transfer process. The timelines are tight and it is not clear as to how the procedures are loaded into the vehicle and when and how the process is initiated.

This concludes the splinter comments.

After having been reasonable and cooperative up to now, the Shuttle Safety Board has recently become very inflexible about hydrogen peroxide. This appears to be a direct function of the increased visibility that the project "enjoys" at JSC. Frank Benz, formerly of WSTF and now at JSC has a firm opinion that peroxide is unsafe and that there is a lack of sufficient data to prove it otherwise.

This position is not supported by fact. There are huge volumes of data generated in the 1960's. While there was some difficulty in corroborating those data with recent tests, the discrepancy was traced to differences in test techniques with the modern methods being unsuitable to peroxide. The latest results from material tests at FMC look very good and agree very well with the old data. In short, there seems little or no reason for concern. However, these emotional prejudices may be hard to overcome.

The material choice for the RCS tank is being revisited. Aluminum alloy 6061 is only slightly inferior to 5254 in terms of peroxide compatibility and, being significantly stronger can potentially save significant weight.

A recently expressed concern is that of decomposition caused by adiabatic heating when the liquid is introduced into an evacuated line. Hydrazine is prone to this problem, which caused an explosion in a communications satellite (one incident out of many hundreds of times that this has been done.) Data on peroxide indicate that it is not prone to this problem so it is probably not a real concern.

A question was raised regarding a 9-valve relief valve array being discussed for the X-37 propellant tanks in the Shuttle. This arises from a literal interpretation of two requirements: 1) three inhibits against inadvertent venting of fluids into the payload bay and 2) three inhibits against over-pressurizing the tanks. Blindly following this logic leads to three valves in a row in one line but with a branch at each valve in case that valve jams. To meet the requirement, each branch then must have three relief valves in it. This leads to a nine-valve array. No one thinks that this is viable because of weight, cost, and complexity. Boeing and MSFC propulsion personnel are working to develop a concept using fewer valves and incorporating some burst disks.

### **Launch Vehicle**

Since the X-37 is now a primary payload and must bear the full brunt of Shuttle costs, other launch options are again of interest. I have been discussing this with cognizant Boeing personnel. It appears that most of the required information is available from the studies done about a year ago before the decision was made to go to Shuttle. I have advised Boeing to gather the data previously done, update it as seems suitable based upon advancement in the design process, and put together a summary that will help in comparison of the options. I suggested that, if they have a recommendation, they should make it.

A briefing was presented to the NASA program office on 6 December summarizing Boeing's approach. Boeing feels that the Delta IV M+ with a 5 meter fairing and two solid strap-ons is the proper choice for an ELV.

In the initial cost evaluation however, the cost of the Shuttle launch comes in at around \$81M to \$86M while the ELV is about \$117M. The primary difference is the \$67M direct price for the Shuttle versus around \$93M for the Delta IV. This does not, of course, include the hidden cost of Shuttle; the numerous reviews and extra analyses required. This can only be made worse by the recent increase in hostility toward peroxide. An additional consideration is that no version of Delta IV has yet flown.

### **Flight Sciences**

The wind tunnel testing continues essentially on schedule. The RCS model is about to enter the C tunnel at LaRC for test in the Mach 10 regime. The lower speed tests are complete and the preliminary results look very good. Correlation with CFD is also very



good. Some minor problems are delaying tunnel entry, but this should not substantially impact the completion date.

### **Avionics**

The current cabling weight is 476 lbs for 150 or perhaps over 200 cable sets (there is some uncertainty). However, the total expected number of cable sets is 370. The potential for a substantial weight increase is significant. This results from poor estimating. Personnel simply left out a large number of cables in their original numbers.

The SIGI power supply for GPS/INS is qualified to aircraft specifications. Requalification is required from compliance with the common specification. Changes to the hardware will probably be required. This will cost some hundreds of thousands of dollars. One wonders why this seems to be coming up as a surprise this far into the program.

### **G., N., and C**

Because the hinge moments were severely underestimated, flaperon deflection is being limited to 8 or 9 degrees as the vehicle slows toward the transonic regime. This is not a popular idea with controls personnel who want all the control authority they can get during this critical phase. In the absence of any serious disturbance (e.g., a strong gust) the limited deflection is probably acceptable but a major disturbance could be trouble.

The G, N, &C staff is carefully evaluating the requirements for control deflection during the low supersonic and transonic speed regimes. The loads developed from this analysis will then be fed back to the actuator and structures personnel to ascertain what changes may be required to meet the control requirements. This may have some weight impact but the vehicle cannot be undercontrolled in a critical flight regime. It is almost certain that the full deflection of 40 degrees will not be required, thus the hinge moments and resulting loads may not be as severe as once thought. However the vehicle will certainly require more control authority than can be afforded by the 9 degree (or thereabouts) limit that the current structure and actuator capability imposes, Boeing management is taking the position that there is no significant problem but anything that may cause more weight growth is at least undesirable at this point.

### **Structure**

The collapsed core on the lower fuselage panel has been cut out in preparation for replacement. The cutout of the core in the lower fuselage corners was last reported in the layout process preparatory to beginning the repair.

## **Operations**

The C-band beacon continues to be an issue. DFRC is hard over that they want it. Apparently the genesis of this demand is that on one Shuttle mission some years ago, all the radars locked up on a 747 rather than the Shuttle for some period. So now they demand a beacon with an identifier.

The practical fact appears to be that telemetry can lock on as the vehicle comes over the horizon and should be satisfactory. However, any interruption in TM could be an excuse to destroy the vehicle. The it will be a "We told your so" situation. The C-MIGITS dropouts are probably adding fuel to the fire even though the systems involved are entirely different.

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13 January 2001

**To:** Edgar W. Nicks  
**From:** Jim French  
**Subject:** X-37 Weekly Report – 13 January 2001

C: S. Turner, Lt. Col. Johannessen, M. Harris, B. Armstrong, S. Stewart, Maj. Titus

### **X-40A**

Work continues to resolve the C-MIGITS problem. Taxi tests are now planned for 17 January, the next captive carry for 24 January and a drop early in February. Boeing's budget for this activity officially runs out at the end of February although they could probably extend the effort through March. The push will be in the direction of finishing by the end of February if possible. The helicopter crew is lost after 1 April.

Extensive data recording on C-MIGITS indicates that the microtracker resets occur when the computer receives a long message from the dGPS. Partial messages are rejected but cause no problem. Even if this is indeed the problem, what to do about it, in terms of changing the system, is not clear. Boeing has analyzed the problem and feels that they could safely turn off the dGPS just before drop. The inertial system is sufficiently stable that it could carry out the flight to the runway without further dGPS updates. If this concept holds up, this is probably the best solution. Given the short duration of the flight, it seems unlikely that the INS would drift far enough to cause a problem. There is a concern that the drop transient might cause a reset or some other problem. This needs to be resolved because it is highly undesirable whether the dGPS is on or not.

Just to add to the headaches, there has been about 1.5 inches of rain. The dry lakebed is now the wet lakebed. Even with no more rain, the lakebed runways are expected to be closed into February. If there is more rain, the only hope of timely completion of the program may be to use the hard surface runways if Safety will allow it. Boeing wants a first flight on 5 February. That would make the hard surface runway (Rwy 22) essential. Briefings to the Base Commander on this issue are in progress.

## **X-37**

### **Vehicle Design**

The weight problem discussed previously is, of course, a concern to Boeing. After the major jump that occurred in November / December, they have begun intensively working the problem. Apparently there are several, not specified, weight reduction approaches being considered. They are also looking at increasing the weight capability of the vehicle. The limitations on weight are 1) planform loading and the resultant heating during entry, and 2) landing gear capability. Probably there are others coming into play as weight increases. The Chief Engineer expresses confidence that with the combination of increased capability and reduced weight, Boeing can come to Rollout with acceptable weight margin. This, of course, remains to be seen.

### **Propulsion**

In an earlier report, it was mentioned that use of 6061 aluminum instead of 5254 was being considered. That has been dropped for the main tank but is still being studied for the RCS tank. The final result of this study is expected by the end of January. The weight saving from using the stronger material may be significant.

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24 February 2001

**To:** Edgar W. Nicks  
**From:** Jim French  
**Subject:** X-37 Monthly Report – February, 2001

C: S. Turner, Lt. Col. Johannessen, M. Harris, J. Sisk, A. Nolen, T. Taylor, S. Stewart,  
Maj. Titus

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### **X-40A**

A captive flight was conducted on the morning of 31 January. It was successful other than minor anomalies. An anomaly recognized prior to the flight was lack of continuity in the drop signal cable. While this would have precluded an emergency jettison of the vehicle, the helicopter crew felt that the risk was minimal and elected to proceed. The cable had checked out correctly the day before so the reason for the problem is not clear. One more successful captive flight was required before a free flight.

Two remaining issues required resolution prior to a free flight. The Divide by Zero issue has not yet been put to bed. There was also the concern with C-MIGITS occasionally losing satellites during simulator test must be dealt with. The Divide by Zero issue was concluded to be no problem and the C-MIGITS issue a simulation problem.

Approval for testing was finally received from both the EAFC Base Commander and the MSFC Center Director during the second week of February. The Base Command approved use of the hard surface runway flight at any time but expressed a preference for weekends, at least for the first one.

The next captive flight was scheduled to go off on Saturday the 10<sup>th</sup>. This would have allowed a free flight on Tuesday the 13<sup>th</sup>. Weather prevented this flight.

Monday and Wednesday of the week of the 12<sup>th</sup> were backups for the captive flight but battery charge time and the need to have the runway free for the Shuttle preclude a free flight after a Monday / Wednesday captive. Because of pilot /crew availability, runway

work, Shuttle, and holidays, the only dates left in February for flight operations were 20 through 22 and possibly the 24<sup>th</sup>.

After many delays, the next captive flight lifted off at 0700 hrs. on 14 February. Liftoff was clean and smooth. Generally speaking the flight went well until, at about 9.6 ft. altitude on final descent, an event occurred with the on-board Flight Computer. The computer stopped and could not be started on the ground until the computer was rebooted. It was first reported that, had this event happened on a free flight, the vehicle would most likely have landed perfectly. It was believed that the computer was running satisfactorily, just not communicating. It turned out however, that the computer had indeed frozen. While there was some thought that X-40A might have landed successfully from that altitude even without the computer, it is very unlikely. The vehicle is sufficiently unstable that there is little chance that it would settle on to the runway on its own without further control. Even if it did, the probability that it would roll out successfully without steering is small.

This Flight Computer problem is being investigated but no clear cause has been found as of this report. They have been unable to duplicate the problem. They can cause resets but not a lockup. Some consideration is being given to thermal-vacuum chamber runs with the FC but the most logical answer appears to be to repeat the captive flight. A free flight will be not permitted until this new anomaly is resolved; this means the captive flight will have to be repeated.

Had the "event" turned out not to be a problem, the first free flight could have occurred in the 20-22 February time frame and the second 2-3 March. Assuming a decision having been made that a repeat of the captive flight was needed, it was decided to try for 24 February. Unfortunately this did not allow sufficient time to get the helicopter crew back from Alabama. The repeat captive flight is now scheduled for 2 March with 3<sup>rd</sup> and 4<sup>th</sup> for backup. In the interim, crane tests will be performed to simulate the final few feet of descent. This is scheduled for the 26<sup>th</sup>. A thermal vacuum test for the FC will take place on Tuesday

There is some thought that the helicopter may have to return to Ft. Rucker for maintenance. If this happens, it will seriously impact cost and schedule. The Shuttle is scheduled for a 5 March launch. This may impact runway availability.

A lakebed landing is no longer an option for a free flight. Heavy rains in mid-month have essentially filled it with water. The lakebed runways may not be available until May or June. It is fortunate that approval finally came through for the hard surface runway.

Dale Shell has raised the issue of whether it is worthwhile to do a freeflight. If we have a major failure and lose the vehicle, that will put a very bad light on the program. It is getting late enough that any flight data will have little impact. Given the cost and

personnel use problems caused by X-40A, it may be that this question is worth thinking through.

## X-37

### Program

Boeing is working out a new schedule aimed at dealing with the major funding shortage during the current year.

Several weeks ago, I raised the somewhat heretical idea that perhaps the B-52 flight did not provide enough information to be worth the cost and trouble. I have been investigating the question with some Boeing personnel. The answers so far have tended to support my original premise although not completely. The areas in which aerodynamic trouble might be expected are the transonic regime, Mach 0.9 to 1.2, and at touchdown. The B-52 flights get close to the lower end of the transonic regime but do not reach the real conditions of interest. The B-52 drops do provide information on flare and touchdown but those data could be obtained on a helicopter drop test (like X-40A), a much cheaper and simpler operation that would not impact vehicle structure as the B-52 loads do. The greater altitude, longer flight time and higher speed of the B-52 tests allow the X-37 to fly the Heading Alignment Circle (HAC). The people most interested in this are not the aerodynamicists but rather the G,N.&C sensor people. I suspect that their concern arises from worry about whether the GPS can retain lock as the vehicle comes around the HAC at a steep bank angle. Clearly this is a crucial issue and must be answered. One might question whether the B-52 test is the only way answer it. An aircraft test of the guidance system might answer it just as well. The results of the B-52 flights are clearly desirable but are they worth the impact on the program? I believe that there is enough doubt as to the answer to that question to make further investigation worthwhile. I recommend that eliminating of the B-52 flights in favor of alternate approaches be evaluated.

### Weight

On paper, the vehicle weight has not increased greatly since the last report. That is, to a degree, an artifact of the holidays when not much work was done. The current weight estimate shows 6636 lbs., about 160 lbs. below the limit that can be achieved with placards on vehicle operation. The currently catalogued potential weight increases and decreases are about equal. However, this does not include the impact of the cable weight underestimate reported previously. That is carried as a TBD. The estimate of this weight increase is expected to be available this week and it is expected to be large. Effort is being made to minimize the impact but only so much can be done. Going to fiberoptics

has been suggested and would save a great deal of weight but it is a bit late for changes of that magnitude.

A Weights Tiger Team is looking at ways to reduce weight but it is a difficult proposition.

### **Propulsion**

An X-37 Propulsion TIM was held at MSFC the week of 5 February. The purpose of this meeting was twofold: to exchange technical data and to try to smooth out the very rocky relationship between MSFC propulsion and Boeing Seal Beach propulsion personnel.

In general, I would characterize the meeting as successful and worthwhile. The technical interchange was good. Perhaps more significantly there was considerable discussion of the relationship between the organizations and the persons most involved in the friction were face-to-face. It appeared that these persons were making a concentrated effort to get along. That attitude, along with better communications will solve the problem.

It became clear that much of the problem lies in failure of communication and coordination. In particular, the unfortunate events at the last PSRP meeting, while exacerbated by the personalities involved, could probably have been avoided entirely by better pre-meeting coordination. Weekly telecons and monthly face-to-face meetings should greatly improve the situation. There will probably be complaints about the time involved, given the limited staff, but, nevertheless, I feel that it is worthwhile.

The discussions of the Brassboard test article clearly indicate the importance of that item. This is especially true since the Brassboard activity is defined as including a number of smaller preliminary tests. These latter would include, among other things, tests of representative line sections filled with peroxide and held in vertical or horizontal attitudes to investigate peroxide decomposition in an environment more typical of an operational situation. This sort of information is vital for actual systems design and safety-related analysis.

One issue that was raised involves the possibility of eliminating the AR2-3 main engine in favor of additional, perhaps larger, hydrogen peroxide axial thrusters. Boeing claims that this will save 300 to 500 lb. dry weight and several million dollars. Delta V capability would be about 1200 ft/sec maximum. These numbers may be somewhat biased by Boeing project management's desire to eliminate MPS.

Although it can be correctly stated that most of the X-37 technology demonstrations, on the two planned flights, can be achieved with monopropellant system (the exception being the one dealing with propulsion technology), there are other arguments for retaining the AR2-3. One such argument is the perception that the program is further



reducing its capabilities. This could be damaging in the eyes of Center management and Hq.

Additionally, eliminating the engine will reduce traceability to future Air Force applications. It may be argued that this isn't a major issue since USAF interest appears limited. This may change in the new administration, particularly if an officer like BG Worden moves into a critical position.

Finally, removal of the engine means the X-37 is absolutely locked in to the Shuttle or Delta IV Heavy for launch. Retention of significant delta V capability may open the door to use of Atlas V or Delta IV Medium (assuming adequate fairing diameter).

The Tiger team on hydrogen peroxide compatibility seems a good thing and seems to be well run. The issues they propose to address are valid. The investigation of adiabatic compression detonation (ADC) that they propose is worth doing. There is some lore that says it isn't a problem at 90% concentration but it would be nice to have that shown. This work fits nicely into the propulsion technology line item. Programs such as SMV that require more advanced propulsion will want to investigate higher concentrations, e.g. 98%. These tests and the procedures and facilities developed for them can lead smoothly into investigations of the (ADC) characteristics of higher concentration peroxide.

The majority of my activity the week of 12 February concerned the propulsion system, most particularly following up on the TIM held at MSFC during the week of 5 February.

I have reviewed the materials test plan created by the Tiger Team. It is very thorough. Upon conclusion, it will contribute significantly to the database for hydrogen peroxide propulsion systems. All the A-series tests, while focused upon X-37 materials, are basic materials characterization tests and have broad applicability. Of more direct support to X-37 are the C, D, and E tests. (The one B test is not a test at all but more of an evaluation and screening activity). The C & D series tests are tests of actual X-37 type components in peroxide. These clearly have direct applicability to X-37. The E-series refers to tests on the Brassboard propulsion test article, also clearly of direct applicability. The details of some of these tests, particularly the Brassboard, are yet to be defined. This definition process will bear watching to make sure that the greatest benefit is derived.

It might be argued that the A-series tests could be eliminated in part or in total in favor of the results of the C, D, and E tests. I believe that this is true. However, given that we are dealing with Shuttle safety, I fear that the probability of eliminating any of the tests is very low.

The screening tests for Adiabatic Compression Detonation is probably worth doing just to define whether we have the problem. The recent event at Stennis (even though it occurred with a 98% peroxide) will have that concern foremost in many minds.

Rocketdyne reports that they have been ordered to slow down to a very low level of operation. Much of the fabrication and assembly work is being stopped and people relocated. The slow down is being blamed on lack of a decision regarding cancellation or retention of the MPS. If the program is slowed enough, the detrimental effect may be as bad as shutting down the program for a year as was previously discussed.

The RCS system is generally going well. The only significant problem in the past few weeks was the discovery that a required change to the thruster valves had not been made. Last year it was discovered that entry heat soak heated the valve coils to about 150F. This adversely affected valve response. The valves were specified at 20 msec responses at 70F. The increased resistance at the higher temperature slowed the valves to an unacceptable degree. The manufacturer was directed to correct this with larger coils but somehow the contractual word never got through. This was recently discovered and is now being corrected. Because of the slowed schedule, this should not be an issue.

The trade between 5254 and 6061 aluminum for the RCS tank continues. In compatibility tests, 6061 is worse than 5254 but, on the other hand, it is better than the bladder material so there seems little reason not to go to the higher strength alloy and save 5 or 6 pounds.

### **Structure**

Work continues on repair of the lower fuselage. The honeycomb has been cut away and the team is looking at number and orientation of plies to give the right strength and stiffness. Repair of this fuselage section is the longest pole in the technical schedule right now but, given the probable schedule stretch out due to funding problems, the repair will probably not be an issue.

Analysis of loads in the repaired area is being conducted to ascertain whether additional structural members will be required.

### **Flight Sciences**

This area continues to be one of the most successful on the program.

Wind tunnel testing at Ames Research Center is complete as is the Mach 10 RCS testing on Tunnel C at AEDC. Data continue to look good. The CFD for RCS testing correlates well with the tunnel data.

In general, however, there is some discrepancy between Boeing's CFD and the aerodynamic flow shown by the wind tunnels. LaRC's CFD matches the observed data much better. It is generally felt that the mismatch is due to the chosen CFD grid and that a little tweaking of the grid will bring things into alignment. This certainly points up the

risks of depending totally on CFD (as Orbital Sciences did on Pegasus). Real data are needed to anchor the analysis. Otherwise CFD can lead to erroneous conclusions. Once your grid choice and other characteristics are anchored by real data, the use of CFD to expand the range of conditions becomes a powerful and cost effective tool.

The next tunnel entry is scheduled for April in the Polysonic tunnel. The purpose of these tests will be to deal with details such as hinges, control surface gaps, etc. This will conclude the currently planned wind tunnel tests. However, the Flight Sciences Lead Engineer is continuing to push for one more entry to investigate aerodynamics at high altitudes, such as 250,000 ft. because he feels that knowledge in that regime is insufficient and that a better understanding might be beneficial in solving some of the trajectory questions discussed below.

Because of the weight problem, a Flight Sciences Tiger Team is investigating increasing the weight capacity of the X-37. The two major limitations are entry heating with increased planform loading and wheel touchdown loads. The team is looking at flying the high heat rate portion of the trajectory at a higher angle of attack (hence the interest in high altitude aerodynamics). The higher angle of attack should result in reduced heating.

It will cost range and entry performance because of increased drag but there is no real requirement for high range or cross range so this is probably acceptable. It is probably possible to increase the wheel/tire size slightly thus allowing an increase in landing weight. The current best guess is an increase in allowable weight up to 7000 lbs. (vs. the current 6800).

### **Launch Vehicle**

The choice of launch vehicle is still in debate. Boeing management really favors the ELV as an easier option for them. The greater line item cost of the ELV is a negative but, as observed in the past, this begs the question of the hidden costs of Shuttle.

Boeing is coming close to defining launch vehicle-related requirements that will force X-37 to use Delta IV Medium for the ELV option. In order to prevent that, NASA needs to define requirements such that the characteristics of all possible candidates are enveloped. In other words, specify such that, if X-37 meets the specifications, it can fly on any of the candidates. This is commonly done with comsats where a particular model may fly on a half dozen different launch vehicles.

The enveloping specifications should include mechanical vibration, acoustics, longitudinal and lateral accelerations, EMI, and probably others. A major discriminator is the availability of an adequate size fairing since it is probably too difficult to go enshrouded at this point.

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31 March 2001

**To:** Jay Laue, SAIC  
**From:** Jim French  
**Subject:** **Monthly Report for March**

C: S. Turner, Lt. Col. Johannessen, M. Harris, J. Sisk, A. Nolen, T. Taylor, S. Stewart,  
Maj. Titus, E. Nicks

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### **X-40A**

It has been decided that two captive flights with no problems are required before a free-flight will be approved.

A computer problem occurred during flight preparation on 2 March and caused the flight to be cancelled. The problem was a bit error related to the flash card. Three attempts resulted in the same error. A power-off reset did not cure the problem. During diagnostics, the error occurred again. The test was cancelled due to this problem and weather. Later during further tests, the problem cleared itself.

A successful captive flight was conducted on 5 March. There were some problems with short notice for personnel. Winds aloft were very strong making operations difficult. The weather would not have permitted a free flight (also the case on 2 March). Four successful passes were made. The dGPS performed well.

The Army crew became unexpectedly available, which opened the possibility of a captive flight on 7 March, and a drop the following weekend. The 7<sup>th</sup> flight was scrubbed due to early weather and then a loss of telemetry services. The next plan was for Saturday the 10<sup>th</sup>.

A very successful captive flight occurred on 10 March. This cleared the way for a free flight on 14 March. The only obvious discrepancy was an unexplained flat tire. No problem on a captive flight but obviously undesirable for a free flight.

The only significant problem on the 3/10 captive flight, other than the flat tire, was a few GPS dropouts. The latter were determined to be caused by a low number of GPS satellites in view. It would not have been acceptable for free flight. No problem has been found with the tire. The entire assembly was replaced just to be sure.

Everything appeared to be "Go" for a flight on the morning of Wednesday the 14<sup>th</sup>.

The first free-flight of the X-40A occurred at 0940 PST on 14 March on the second attempt. Two dry passes were conducted prior to attempting a hot or drop pass. The first attempted hot pass was aborted because winds were possibly out of tolerance at the go/no-go point (although winds were okay at release time). The pass was continued without a drop as a practice/verification run. The second pass experienced no problems. Helicopter handling throughout was impressive in its precision.

The free-flight appeared very smooth and solid on the video received at Seal Beach. Although one person claimed to see a roll oscillation similar to that experienced during the Holloman flight, it was so slight as to be invisible to the rest of us if indeed it occurred. The previous oscillations were only about one degree, very difficult to detect visually. The data do not appear to bear out the oscillation.

Touchdown appeared smooth with no obvious bounce. Rollout appeared well-controlled and braking smooth. From the camera angle, it was difficult to tell how close to centerline the vehicle was, but it was clearly in the rubber marks left by aircraft operations. Later reports disclosed that it was about 15 feet off centerline at touchdown and 7.9 feet off centerline at wheel stop. At the latter point, C-MIGITS thought it was 2 feet off. Touchdown location along the runway was about 1250 feet.

Recovery operations appeared to encounter no problems.

Boeing had hoped to get approval for the next flight to occur on Wednesday, 3 April. However the Range did not approve this and thus the alternate of 2 April was selected. If all goes well, the next flight is planned for Saturday 6 April.

During handling of the X-40A after flight, creaking sound was heard. This turned out to be caused by a small disbond in some structure in the nose landing gear area. This has been repaired.

## **X-37**

### **Program**

With the cancellation of the X-33 and X-34 efforts, there will be increased visibility of the X-37 program and perhaps more help than we really want. The psychology of the center and Headquarters management will be that this program has to work in order to show that NASA in general and MSFC in particular can manage a successful X program. The more support that can be garnered for the program the better. The vehicle is in serious weight problems that must be solved for the mission to be successful. I strongly recommend that we work closely with Boeing to try to develop a solution to the problem as soon as possible.

It appears that, rightly or wrongly, Boeing was expecting the effort under 8-30 to be a relatively simple extension of the current agreement and was taken by surprise by the requirement to recast the proposal in a new format and rework the budget to the extent that they are doing.

I the review schedule for the rest of the program is as intense as has been reported to me, it may be a valid question as to whether this is too much of a good thing. Without knowing the details, it is difficult to assess, but it may be worth considering whether a very intensive review schedule is cost-effective.

### **Vehicle Design**

With the probability of changing to an ELV launch from the Shuttle, the vehicle will probably become much lighter as various Shuttle-edicted redundancy and other hardware is removed. This will help relieve the weight problem even if there continues to be only one airframe. If we end up with two airframes, the second unit can be optimized for space flight and include all the lessons learned on the first one. This will result in further weight savings.

### **Flight Sciences**

Data analysis of wind tunnel data continues. Things continue to look good except for the previously discussed discrepancy in the Mach 6 to 10 regime. AEDC and NASA LaRC tunnel data disagree with one another and with CFD. This discrepancy has yet to be resolved.

On a positive note, it appears that  $L/D$  at landing will be about 4.5. This is about 0.5 greater than expected. The increase will make the X-37 much easier to flare and land.

The entry into the Polysonic Wind Tunnel has been pushed back to June. Since it is the last planned tunnel entry, people keep adding test points they wish to see. As a result the test has grown much larger and more expensive. This is the main reason for the delay.

I have reviewed the preliminary report from the RCS test conducted in the NASA LaRC and AEDC wind tunnels. I have been concerned about the possibility of dangerous interactions between the jets and the airstream. Shockwaves formed by such an interaction impinging upon aerodynamic surfaces can cause control problems. One such interaction on X-33 required extensive reconfiguration of the RCS to preclude loss of vehicle control. The tests on the X-37 models seem to put this concern to rest. While there are strong interactions between the jets and the airstream, there is nothing that indicates the sort of dangerous cross coupling seen on X-33. The data from the tunnels at the two facilities compare well and both compare well to CFD analysis.

Models of the thrusters were tested prior to their incorporation into vehicle models to ensure proper simulation and that the jets were well characterized. For these tests, the jets used air. Innovative design approaches greatly simplified model changes test to test. Since the forward jets are not used on entry, only aft jets were simulated. Because of vehicle symmetry, it was not necessary to simulate all the aft jets. The models had moveable control surfaces to investigate the significance of control deflection.

The relationship of jet interaction effect with angle of attack is non-linear but consistent. There is no obvious correlation with sideslip angle. There is a Mach number effect that is strongest at the lower end of the test range (M 2.5 to M10). The momentum ratio of the jet to the free stream appears to be a suitable jet interaction correlation parameter. Jet interactions are affected by ruddervator motion on the same side. Flaperon and body flap deflections are less significant. There is little or no impact of opposite side controls.

In general, the problem seems to be well understood and there should be no significant issues.

## **Structure**

The repair of the lower fuselage skin section that was damaged upon removal from the mold has been repaired. As noted previously, the repair consisted of cutting out the honeycomb in the damaged lower corner areas and laminating new graphite epoxy layers in the areas. NDE inspection of the repaired areas shows a few minor disbonds but nothing significant. Work has proceeded on building up the structure even though a decision to build up a second airframe would probably require some changes in this airframe.

The suggestion has been made that, rather than building one more airframe for an orbital vehicle and using the current repaired unit for the atmospheric tests, that two new airframes be built and the current one scrapped. While the idea of having two new

airframes that incorporate all the lessons learned from the first one but do not have all the repairs is attractive. It may not be practical from the cost and schedule viewpoint. It is estimated that building a second new airframe would add about 6 months to the project, about 4 of which is material acquisition.

The repair of the first unit is complete except for repair of some minor separations discovered in NDE. This unit should be sound and ready to go I am told.

Currently, further assembly of the airframe is on hold pending some modifications required by loads analysis. The aft frame was originally intended to be secured to the skin by bonding to the face sheet of the honeycomb that forms the skin. This joint may not be sufficiently strong. It may be necessary to cut out the inner face sheet and honeycomb and lay in doublers (similar to what was done in the lower fuselage corners). Then the frame would be installed using mechanical fasteners, resulting in a stronger joint. At last report, a decision on whether to proceed with this change was being considered by the Chief Engineer.

### **Propulsion**

A Rough Order of Magnitude estimate is being prepared for cost and schedule to resume a full-scale composite tank effort. Again, I feel that it would be worthwhile to investigate the technology being developed in the USFE program. That is a much more complex tank than required for X-37.

Work at Rocketdyne was slowed to a crawl prior to the decision to retain the MPS. The hardware was being boxed for storage and personnel were looking for new assignments effective as of the completion of the storage preparation and documentation.

Subcontractors on tasks such as cutting the screens are being allowed to complete their work. Rocketdyne has been directed to hold expenditures to the range between \$0 and \$5000 per week.

The decision being made to get the AR2-3 program moving again, it appears that the action may still be too slow to retain the current cadre of experienced personnel. In a few weeks most will be gone and, very likely, not recoverable. As a result, corporate memory and continuity will be lost. Rocketdyne has been told that they will be funded by 1 July. This is too late to prevent loss of key personnel. It might be worth considering to provide enough funding to retain one or two key people.

It appears that the Propulsion organization has agreement on the peroxide compatibility testing plan. I have not seen the new plan but expect that it is some what pared down from the original version produced by the Tiger Team. As noted in an earlier report, that version, while every test was worth doing, was probably more than was needed for X-37



## **Launch Vehicle**

When Boeing resurrected the idea of flying on expendable vehicle recently, I reported that their choice was the Delta IV Heavy. This is incorrect and was based upon my misinterpretation of something I was told. I am indebted to Lt. Col. Johannessen for pointing out the error. Delta IV Heavy was indeed a possible choice in an earlier study under the assumption that X-37 could be dual manifested with another payload to defray cost. At this point however the Delta IV Heavy configuration is uncertain and there are even hints that it may never be built. The chosen version at this point is a Delta IV Medium 5-2. This means a common core booster with a 5 meter nose fairing and two solid rocket boosters. Boeing does state that, if Delta IV heavy comes to be, they would consider it if they could find another compatible payload with which they could dual manifest. The probability of this is low.

It appears that the launch vehicle will be some version of Delta. I believe that this is a good move since the Shuttle complicates things tremendously. The apparent campaign at JSC to prevent the X-37 (and its hydrogen peroxide) from flying in Shuttle makes things much worse than normal.

The baseline Delta is the Delta IV Medium+ 5.2. However, it appears that there is a viable possibility that one or two of the higher performing Delta II vehicles can do the job. With the Delta II, it will be necessary for the X-37 to launch unshrouded. Flying shrouded, as on Delta IV, makes life relatively simple. However, an unshrouded launch will require extensive aerodynamics and possibly even coordinating X-37 controls with the Delta control system to perform load alleviation. One argument for going this route is that the most likely applications for an operational vehicle are unshrouded and this would allow these issues to be addressed up front.

A dark horse candidate also is Sea Launch, which will have a 5 m shroud in the time period of interest. Some concern exists about ITAR issues but it is felt that these can be addressed by having the encapsulation done by Boeing personnel only.

## **G.N.&C**

Guidance is looking good. No software is being written as yet but the subsystems are becoming well characterized.

It may be necessary to go to larger motors on the actuators. The high rates required on the body flap and ruddervators are causing unacceptable heating of the motor coils. Even though not all actuators will require the larger motors, it may be that all the actuators will be changed for commonality. The weight impact may be a factor.

The biggest problem worrying the G.N.&C is the B-52 aerodynamics and how it interacts with the X-37. A severe wing drop and yaw is expected. This was experienced on X-15.

It is less of a problem for wingless vehicles like X-38. It would not be a big problem for X-37 except for DFRC's insistence on dropping with controls locked.

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28 April 2001

**To:** Jay Laue, SAIC  
**From:** Jim French  
**Subject:** **Monthly Report for April**

C: S. Turner, Lt. Col. Johannessen, M. Harris, J. Sisk, A. Nolen, T. Taylor, S. Stewart, J. McDougal, Maj. Titus, E. Nicks

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### **X-40A**

It was planned that Flt.2 would include an elevator doublet (nose up – nose down). Flt. 3 would include a rudder pulse and an aileron doublet. Flt. 4 would repeat inputs from 2 & 3 as required to get necessary data. Details of subsequent flights have not yet been defined. If the early flights go well, some of those later flights may be cancelled.

Boeing began to consider what options might improve their chances of flight. One question is, what could be done to increase the headwind placard values. The other question involved using runway 04 rather than 22 and landing with a tailwind. This needs to be looked at very carefully. Landing with a tailwind has lots of potential significance. A tailwind results in higher speed on the runway with impact on tires, brakes, and stopping distance. It also raises the specter of overshooting the runway. Some aircraft act a little squirrely in a downwind landing because of different ground effects. None of this says it is a bad idea, just one to be handled with care.

On Thursday 12 April, X-40A was launched and flew to a successful landing at about 0847 on the second hot pass. The PID was executed and was observed by ground personnel. Landing appeared normal and very close to expected parameters.

Following the 2<sup>nd</sup> flight, the team was prepared for another flight on Saturday 14 April or Thursday 19 April. The weather outlook for both days was poor.

A flight was attempted on 19 April but was scrubbed in flight because of winds aloft being out of limits and because the RAJPO signal-to-noise ratio was unacceptably low.

Initial investigation of the RAJPO problem did not uncover any very specific answers. It has been suggested that the cause was the current high level of solar activity.

The flight test scheduled for 24 April was cancelled because no helicopter pilot was available. The test was rescheduled for Thursday 26 April. The flight, the third of the X-37 series, went off without a hitch. Touchdown was 10 feet to one side of centerline and wheel stop 8 feet on the other side.

The helicopter is scheduled for maintenance over the 28/29 April weekend. Possible dates for the next flight are Tuesday, 1 May, Thursday, 3 May, and Saturday 5 May. The 1 May date is doubtful because of the possibility of a Shuttle landing on the 2<sup>nd</sup>. If the next flight slips to Thursday the 3<sup>rd</sup> then the one after will be scheduled for the 8<sup>th</sup>.

Work is progressing on getting some of the lakebed runways operational again. Runways 07/25 and 09/27 are candidates. Boeing is evaluating changes required to use these runways when they are ready but trying to minimize interference of this with preparation for the next flight.

## **X-37**

### **Program**

A Technical Interchange Meeting, in some sense a replacement for a CDR, took place on 3, 4, and 5 April at Boeing Seal Beach. I participated primarily in the propulsion meetings, but also visited meetings on the Thermal Protection System, GN & C and Software, and Structures and Materials.

The contract negotiations continue to drag on. There is evidence of concern among the rank and file staff as to whether the project will actually go forward.

### **Vehicle Design**

Very little is happening as regards the weight of the orbital vehicle. Most of the attention is focused on the Air-Launched Test Vehicle. Boeing is taking the approach that either there will be two tail numbers, the ALTV and an orbital vehicle, or there will be nothing. Therefore, the more immediate ALTV, for which the hardware actually exists, is receiving most of the attention. While the weight is not as critical as for the orbital vehicle, any weight increase has to fight its way on to the vehicle. This is very wise because the nature of things is such that, as soon as weight is declared to be no problem, the weight will immediately escalate until it becomes a problem. Keeping the lid on from day one will not preclude growth but it will help control it.

It is also true that the ability to build a new airframe that incorporates all the lessons from the first one should allow a much lighter structure for the orbital vehicle. Nevertheless, that vehicle is already overweight. The most stringent weight controls will be required to keep within weight limits. The new structure should help but it is not a panacea.

### **Flight Sciences**

Work continues on refining the wind tunnel data. Detailed investigation of the results from the two tunnels indicates that the discrepancy there resulted from mach gradients formed in the tunnels. At high angles of attack, greater blockage occurs than at lower  $\alpha$ - $\alpha$ . Apparently the two tunnels reacted differently to this situation and produced the discrepancies in data. Correction factors for the Mach gradients have been developed that bring data from the two tunnels into good agreement. Some of the errors in the LaRC data, involving incorrect lengths, have been corrected, further improving the correlation between the two tunnels.

CFD is still out of agreement with the two tunnels. This continues to be investigated. Most likely, the problem lies in grid definition, specifically in critical areas. It is vital that the grids be defined properly so as to provide good correlation with the tunnels in the Mach 6 to 10 regime since we will be more dependent on CFD in the higher speed regimes that wind tunnels cannot reach.

Fortunately, hypersonic flow is fairly well behaved so that, once the grid is defined, the CFD results for the higher Mach numbers can be believed. The chemistry and real gas effects caused by heating do cause some concern but, in general, the results will be close. This situation points up again the importance of having real wind tunnel or flight data to anchor CFD analysis. As Orbital Sciences discovered to their dismay some years ago, un-anchored CFD can lead to catastrophic results.

### **Structure and Materials**

The planned C-SiC hot structure has encountered fabrication difficulties. Tests samples to date have been deficient in strength by as much as 50%. Photomicrographs indicate poor penetration of the SiC into the carbon fiber tows. The process involves first depositing pyrolytic graphite on the fibers to provide a basis for the SiC to build up. The SiC is deposited by infiltrating the parent gas into the fiber preforms. It appears that neither the pyrolytic graphite nor the SiC is penetrating into all parts of the tow. Part of the problem may lie in the fact that 3K tow was used in the build up rather than 1K tow. The numbers refer to the number of fibers in the tow. The larger tows may limit penetration of the gas. There are some data indicating loss of strength with carbon-carbon using the large tows, but not as severe as this. The difference may lie in the fact that C-C is usually not made by gas infiltration but rather by saturating with resin, which

is then pyrolyzed. The wicking action with the liquid may draw the liquid in more readily.

Boeing, together with MSFC, is working the problem. It is important to reach a solution since this is the first use of SiC in such structures. Failure could substantially set back application of this material. It is possible to fall back to C-C but that would lose the demonstration of SiC technology. Actually, C-C is such a poor structural material that it may not work in any case.

The PETI-5 body flap is generally doing well although the full potential benefit will not be obtained because of uncertainty in characteristics. This results from the data having been obtained with materials from different sources. Also, the tendency of the titanium core to dig into the fabric and draping of fabric into the core reduce strength. Nevertheless this will provide good data on the use of PETI-5.

Failure of the original body flap design in tests has resulted in incorporation of a centerline rib.

The speed brake encountered serious "stop sign" flutter (by analysis) in its original form. It has been redesigned to be stiffer by adding thicker core in the critical areas.

The possible change to the fuselage structure, as discussed in an earlier report, involving cutting away the inner skin and core and adding a multiple layer doubler to allow use of mechanical fasteners to attach the aft frame will not be done on the first airframe. This modification is only required for orbital flight, not atmospheric. It is clear that Boeing is betting on approval for a second airframe to use for orbital flight. This decision came out late the week of 2 April.

## **Propulsion**

The composite fuel tank does not appear to have major issues. The concept is a two-part lay-up similar to the DC-XA hydrogen tank. Some possible areas of concern involve the inner bellyband for joining the two halves.

Because the access opening is too small to admit a human, the inside belly band cannot be laid up in place as was done for the DC-XA tank. Rather, a form will be made simulating the lower portion of the top half. This will be mated to the lower half, coated with mold release and the bellyband laid up on it and the lower half and cured to the latter. The mold is then removed, the top half moved into place and the joint cured under vacuum bag. Some concern was expressed about this approach but it seems the most practical solution in this situation. Good NDE and proof test should reduce the concern.

The other issue is the use of bonded-on fittings to interface the tank to the vehicle structure. This approach was chosen primarily to avoid fastener penetrations through the

tank wall. Preparation and procedures is critical in achieving adequate joint strength. Many of the joints will be loaded in peel, the most difficult for a bonded fitting.

There appears to be no significant issues with the oxidizer tank. It is a spun and welded 5254-H32 aluminum structure. Welded on pads allow for mechanical attachment of the longerons that interface to the airframe. The alloy is work hardened and welding causes a loss of properties, which must be compensated for in design.

The RCS tank is now 6061 aluminum (as reported a few weeks ago). This is only true of the non-wetted section that is protected from peroxide by the silastic bladder. The sump, exposed to peroxide, is still 5254. This change saves 4 to 14 lbs. depending upon the optimism applied to 5254 properties.

In the rest of the system, lines, fittings, and valve bodies are stainless steel, a Class 2 material. Where possible, peroxide exposed surfaces are electropolished to reduce activity. One problem is the presence of a magnetic 400-series stainless steel. This is required in the latching valves for the latching function. Boeing is evaluating coatings such as zirconium nitride allow use of this material.

The problem with loss of control of NEAR in its first Eros rendezvous was possibly caused by poor propellant slosh modeling. X-37 uses the same mechanical models, which are something of an industry standard, however, the presence of extensive baffling in the tank and development of a coupled GN&C/slosh model should relieve those concerns.

Analysis indicates that most operations are low risk, however; propellant transfer is rated as medium and propellant dump as high risk. The former is considered risky because of limited to no experience with very low flow rate transfer in zero-g. The propellant dump may be high risk because of several factors: the unknown behavior of high flow liquid streams flowing into vacuum, the possibility of propellant ice forming and possibly recontacting the vehicle immediately or a few orbits later, and possible chemical attack on the TPS or adhesive.

There is also a concern regarding accurate control of peroxide loaded into the RCS tank.

A new wrinkle is the use of the axial thrusters to trim out residuals from the MPS burns. This is because the MPS acceleration is relatively high and results in some uncertainty in actual deltaV. The MPS will be programmed to burn slightly short so that a positive makeup deltaV will be required. If both axials fire properly, there is no problem. If one fails but the other fires, the RCS can take out the asymmetric thrust torque and the accelerometer will allow a longer burn to obtain the desired deltaV. If both axials thrusters fail, the two yaw thrusters are canted aft by 30 degrees thus providing an axial component of thrust. To take advantage of this option, the control system must be programmed to use the canted thrusters if it detects no response from the axial thrusters.

When I asked about this, it appeared that Boeing had not thought about it, so it may be something to watch in the future.

The AR2-3 engine program is in good shape as far as hardware is concerned. All catalyst screens were completed before the stand down discussed below. This is prudent given the amount of art as well as science involved. The screens still require the samarium nitrate dip but that is straightforward. Controller boards are complete except for the spare. Some minor damage needs to be polished out of turbine blades. The turbo machinery has been inspected and checked out.

The AR2-3 program continues on hold. All personnel have been reassigned to other programs. Their availability on the proposed 1 July start date is open to question. It is hoped that the Chief Engineer can be recovered but that is not certain.

The RCS system is close to beginning tests of some hardware. Test plans are being developed and work may start in a few weeks. There is some concern that Boeing is not really ready to begin this activity given the uncertainty of the schedule.

A major set of study topics involves analysis of the propellant transfer and dump activities as well as propellant gauging. There are several aspects of this to be looked at. One is the operational aspects of how it is done, how it is controlled, how repeatable, etc. Boeing's analytical tools will be improved for this analysis. At the same time, the system and process is being carefully examined for single-point failures.

### G.N.&C

I have reviewed the software validation and verification information from the TIM. While I am not an expert in the field, it appears that their approach is good and, if thoroughly implemented, should yield a satisfactory result. It is similar to the way software was done on the highly successful DC-X/XA programs and of course is being validated by the X-40A flights.

I remain very concerned about DFRC's insistence that the X-37 be dropped from the B-52 with controls locked. The analysis to date verifies the anecdotal information that the X-37 will be strongly affected by the B-52 flow field and can undergo extreme attitude excursions even during the 1-second period of locked controls now proposed. It would appear that there is serious risk that the vehicle could depart controlled flight. Even if it manages to recover, the possibility of extreme attitudes is most undesirable. If nothing else, considerable loss of altitude is possible. This could have very serious effects on the flight profile.

The new aerodynamic data from Flight Sciences are being passed to the G.N.&C group for evaluation and inclusion in the software. There will probably be no major changes as a result of this but rather refinements of the existing parameters.



The success of the X-40A flights has greatly increased the confidence that the vehicle is well understood, at least in the low speed regime.

By all indications, the X-37 has adequate trim and control authority in the various flight regimes. The high-mounted butterfly tail in conjunction with a wing shows some advantage over a delta planform in that it gains control authority at higher angle of attack and thus avoids the tendency to flip over sometime encountered by delta shapes if a critical angle of attack is exceeded.

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26 May 2001

**To:** Jay Laue  
**From:** Jim French  
**Subject:** **Monthly Report for May 2001**

C: S. Turner, Lt. Col. Johannessen, M. Harris, J. Sisk, A. Nolen, T. Taylor, S. Stewart, J. Mac Dougal, Maj. Titus, E. Nicks

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### **X-40A**

The X-40A plan was for 7 flights total. As was suggested in an earlier report, the possibility of canceling one or two of those flights, if sufficient good quality data were obtained on the earlier flights, would have been considered if the schedule seemed to stretch unacceptably. The Army planned on taking the helicopter back about 18 May, with the possibility of an extension if, say, there was one more flight to go. Getting the seventh flight in before the 18<sup>th</sup> required three flights in two weeks, a frequency not previously demonstrated. Fortunately, there was some tendency by the range to be more lenient in allowing flights to be scheduled since the X-40A starts early and clears the runway quickly. The team rose to the occasion most admirably.

The need to support a possible Shuttle landing precluded a flight on 1 May. The weather was perfect and it would have been a good day to fly. The goal was to get at least one flight off during the week. Thursday 3 May was originally targeted with a backup of Saturday 5 May. However, the Thursday date was scrubbed leaving Saturday as the primary. The fourth flight under the X-37 program was successfully conducted on that date. Winds were 2 to 4 mph. The flight featured increased lateral PIDs and was to release 200 ft. high or low, depending on wind. The next flight was scheduled for 8 May.

Flight number 5 of the X-37 series was successfully conducted on 8 May. The main goal for the last two flights was crosswind landing so weather was important as was runway selection. Flight 6 was scheduled for Friday 11 May with Saturday as a backup. It was not possible to fly on either day. On the 11<sup>th</sup>, no wind data were available because the data taker overslept. On the 12<sup>th</sup>, the winds at altitude were too high for the drogue chute.

The shear tie problem referred to in earlier reports came about through human error caused by over-tightening the front pads that hold the X-40A in position on the strongback. The ties between the vehicle skin and internal bulkhead were cracked. The situation is well explained in a short report by Dale Shell of Schafer Corp.

The issue of crosswind landing is interesting with this vehicle. The relatively fat fuselage and very small wings tend to mean that there could be some blanking of the downwind wing with a strong crosswind. Given the very high landing speed, this does not seem a big problem however.

There are two classical crosswind landing techniques. One is to come down final in a forward slip (cross controlled rudder and aileron), which keeps the vehicle aligned with the runway while flying a little sideways relative to the airflow. This slip is held until touchdown. Alternatively, the vehicle is flown in a crab, that is, heading into the relative wind, until just before touchdown. This means that the vehicle axis is not aligned with the runway. An abrupt rudder input turns the vehicle so that its long axis is aligned with the runway at touchdown. The X-40A will fly the final descent crabbed into the wind. However, rather than a control movement to straighten it out before touchdown, it will be allowed to touch in the crabbed attitude. The landing gear will then pull it straight. This departure from the classical technique is because it is difficult for the guidance system to know the altitude accurately enough to perform the maneuver at the optimum altitude. Too early and the vehicle will build up a sideward drift before touchdown. Too late and it lands in a crab anyhow. The Shuttle uses the same technique and gear sideloads is one of the limitations on Shuttle crosswind.

X-37 will have much better crosswind capability than X-40A because the gear track is wider.

Judging the flare altitude on this vehicle is very critical because of the high sink rate and low L/D aggravated by the small size. While Shuttle has similar characteristics, the very large planform area gives a substantial ground effect that tends to cushion any errors. The X-37/X-40 shape, with its very small wings and small size has very limited ground effect so timing the flare is much more critical.

In order to get more of a crosswind component, the team wanted to fly into lakebed runway 17. This was impossible because of the requirement to redo Ec calculations and to obtain the various approvals. It was thus necessary to continue using the hard surface runway 22 and hope for crosswinds. Boeing calculates that X-40A can handle up to 15 kt crosswind component and would like to actually test it up to 12.5 kt. It seems ironic that, having fought so hard to get permission to use the hard surface runway, now it can't be changed. Chuck Yeager didn't know how easy he had it in 1946.

The team requested two windows each day for the week of 14 May in hope of completing the flight plan. During the return to base from the aborted mission on 12 May, RAJPO

dropped out twice. During preparations for the scheduled 15 May flight it appeared that RAJPO could not see the X-40A at all. This problem was resolved in time for an early morning attempt on 16 May. The problem apparently had to do primarily with the location of the vehicle. And did not appear to be X-37 related at all.

The sixth flight under the X-37 program was successfully conducted on 16 May. The flight plan included a long PID maneuver. A crosswind up to 12.5 kt was desired for this flight but was not mandatory. Initially, the crosswind looked as if it might be close to the desired level for Flight 6. However, it appears that the wind dropped slightly about release time so that, at first look, it is believed that about a 5kt crosswind component was experienced. Touchdown accuracy seemed to be very good.

Most of the rest of the week was available for Flight 7 except for a possible conflict Friday morning. The test was scheduled for Friday morning but that attempt was cancelled due to wind shears in excess of acceptable values.

Flight 7 was successfully conducted on the morning of Saturday, 19 May. To add a bit of drama to the flight, CMIGITS lost GPS 2 sec. after release. The entire flight was made on inertial guidance. Preliminary numbers for landing accuracy look just as good as those flights made with GPS. At this point there is no word on the amount of cross wind. CMIGITS came back on line just after touchdown.

This concludes the effort on X-40A under the X-37 program. Even though it is substantially behind schedule, it was nevertheless a successful program. Boeing's G.N.&C group feel that they have learned a significant amount regarding the low-speed aerodynamics and controllability of the configuration. In addition, a successful flight test series cannot help but improve the morale.

## **X-37**

### **Program**

Some of the IPT leads are concerned by the possible additional 4 months program duration that is understood to be part of the NRA8-30 package. Budgets were done based upon the previous schedule (which was slipped four months from the original). In order to accommodate the additional four months, they will either have to reduce personnel or ask for more money.

### **Vehicle Design**

Boeing questioned the validity of flying a composite fuel tank. The chosen material is well known and widely used in this application so no new technology is being demonstrated. Because of minimum ply considerations in a filament wound composite tank, it was considered quite possible that an aluminum tank would be lighter than a composite in this size range. Given the simple shape, it was almost certainly be cheaper. The real interest in composite tanks was for the peroxide since fuel was deemed no problem. The composite oxidizer tank has been out of the system for a year. When they asked my advice on the subject, I agreed that it made sense to drop the composite fuel tank.

The cost and weight advantages of the aluminum tank appeared valid, so, with MSFC agreement, the requirement for a composite fuel tank was dropped. Paperwork has been initiated to change the fuel tank from composite to aluminum.

Weight is holding reasonably steady for the moment. The weights people are watching very closely to try to prevent any surprises. The decision on the program and hardware changes proposed in NRA 8-30 will be very critical of course.

### **Propulsion**

Rocketdyne is completely out of money and the team is dispersed. The technicians who have done the engine assembly have been laid off and the turbomachinery engineer has resigned. While I understand the fiscal problems that have led to this situation (including Rocketdyne's persistent cost overruns), I continue to fear that loss of key personnel may cause severe problems in the future. The long-term cost may completely overshadow any current savings.

Rocketdyne's restart has now been delayed from 1 June to 1 July. The one bright spot in that area is that it looks as if the AR2-3 Chief Engineer and one other major player will become available from their current programs during the summer so it may be possible to reconstitute the core of the team. I hope that funding becomes available in time to get these critical individuals back on the program.

One of the concerns incident upon the stretchout of the schedule resulting from budget limitations is the impact on small suppliers. Large subcontractors have enough business base to tolerate delays and changes but small companies find such situations difficult and sometimes fatal. A case in point that has concerned Boeing is Castor, the valve supplier. In response to this concern, a partial FDR was held at Castor. This allowed Boeing to make a program payment, which will help keep Castor going. A delta FDR may be required later to cover what was left out of this one.

## TPS

As reported earlier, arc jet tests at the predicted heat flux causes slumping of the leading edge TPS. This is not sufficient to cause failure, but may cause some problems as discussed under Flight Sciences. The TPS personnel think there is a fair chance that no slumping will occur since the aeroheating analysts tend to be very conservative.

Boeing is working on development of new processes for making the RCG coating for the wing leading edge tiles. The suppliers that made the material for Shuttle are no longer qualified. The Shuttle program is looking to qualify a new source since eventually their current supplies will run out. However, they are looking for a new supply two or three years from now. X-37 needs one much sooner, thus the desire to develop a simpler in-house process. They would like to get it done in time to qualify the material for X-37 in the near term. If the tests are done using RCG material borrowed from Shuttle and then a new process is developed, the qualification will have to be repeated. It would obviously be better to get the new process developed sooner. Right now, X-37 is borrowing from Shuttle and it is not clear how long that can continue. Independence is very desirable.

It might be argued that technology development in this area has not been successful since it is predicted that the TPS cannot stand the entry environment. In fact, Boeing and NASA have made significant strides in increasing the capability of TPS tiles over the current state of the art. It is just that the wing leading edge environment on X-37 is so severe that the tiles still cannot survive as reusable units (assuming the temperature and heat flux predictions are correct). The major culprit is the small leading edge radius of the airfoil, a result of the small size of the X-37. I suspect that these tiles would be much more successful on the leading edge of a Shuttle.

## G.N. & C

Some time ago it was mentioned that weight could be saved by changing the philosophy of using the same type of actuator for all functions on the vehicle. Rather the actuators would be more nearly customized, using standard components such as motors, gear boxes, etc. This has now been done and has resulted in saving weight. No cost data are available but it is probable that the penalty is not great since all components are standard.

There appears to be some hope of a solution to the B-52 clearance problem. It appears that, if X-37 drops with the body flap locked in the full down position for the first second, there is no way that X-37 can recontact the B-52 no matter what the other control surfaces do.

If DFRC accepts this (and they appear favorable to doing so) then it will not be necessary to lock the controls at release except for the body flap. The flaperons and ruddervators are then free to control vehicle attitude disturbances caused by the B-52 flow field even as the body flap causes steep pitchdown to avoid the B-52.

The new issue (there is always a new issue) concerns reactivating the body flap. It can be run to the full nose down position and power removed. Power removal will cause it to lock in place. After the first second, power will be reapplied and the flap moved to the proper trim position for flight. The issue relates to how the power is applied. Boeing wants to simply program the flight computer to power up the actuator at the proper time. Safety finds a software solution unacceptable. They want a separation-initiated timer. While this will cost a little weight and money, my inclination is to do it that way. It will be cheaper in the long run than another protracted battle with DFRC over safety.

Conclusion of the X-40A flights should free up personnel to work on X-37.

### **Flight Sciences**

The resolution of the discrepancy between the wind tunnels and CFD is progressing. Some additional corrections to the LaRC wind tunnel seem justified. Boeing will be meeting with LaRC to discuss this since too many corrections begin to sound like "dry-labbing" the data and the Flight Sciences lead wants to avoid that.

As suggested in earlier reports, revision of the CFD grid is needed to improve the fidelity of that simulation. Evidently, when the CFD analysts laid out the grid for the high mach regime, they used a similar grid to that which was used in the lower speed regime. This was not a good idea. The lower speed operation occurs at lower altitude where the higher density means a higher Reynolds Number and a thick boundary layer. The high density gridding is really only needed in the boundary layer. Unfortunately, the higher Mach operation occurs at much higher altitude, which leads to a lower Reynolds Number and a much thicker boundary layer. In fact the laminar boundary layer may reach almost all the way out to the shock. The upshot of all this is that the high density gridding needs to reach much farther from the vehicle in the high altitude/high Mach number regime in order to get a good result. This requires a lot more computation time than the lower altitude model, but is necessary if the CFD results are to be depended upon. The small size of X-37 compared to Shuttle exacerbates the Reynolds Number issue.

As noted above, the results of arc tunnel tests showing that there may be slumping of the TPS on the wing leading edges are a concern. As the TPS slumps, a ridge builds up aft of the stagnation point. This could have detrimental effects upon the airflow. Tripping of the laminar boundary layer could cause increased heating on the wing. It may also effect the pressure distribution that could result in loss of lift or even control problems. It might affect stall angle of attack, which could cause landing problems. Because of these concerns, the upcoming wind tunnel tests will simulate the ridge caused by slumping to determine if there are any detrimental effects. If not, we can proceed as planned. If any of the possible problems are, in fact, observed, some solution will be required. In any case, the leading edge will have to be replaced after each flight if it slumps. This is not a desirable feature in a reusable vehicle.

Much of the heating problem again results from the small size. While the wing is relatively blunt, the small size results in a small radius of curvature. This, in turn causes heating problems. The Shuttle also experiences shock impingement heating on the leading edges, but the much larger size reduces the heating problem. While the X-37 planform has some virtues, one wonders if it is the best option for a small vehicle. A wingless entry vehicle with vertical landing capability would avoid most of these problems.

### **Flight Operations**

A series of range safety meetings is working through the issues with FTS. This seems to be going fairly well. If the decision comes down to switch to an ELV for launch, some of it will have to be redone but much will remain applicable. Some new items such as a propellant tank destruct charge will have to be added.

It is currently planned that X-37 would pick up the FTS receiver units that were being built by L3 Com for the now-cancelled X-33 program. It appears that the only required modification would be to change the tones. This would save about 3 months for the X-37.



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30 June 2001

**To:** Edgar W. Nicks  
**From:** Jim French  
**Subject:** **Monthly Report for 30 June 2001**

C: S. Turner, Lt. Col. Johannessen, M. Harris, J. Sisk, A. Nolen, T. Taylor, S. Stewart,  
Maj. Titus

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### **X-40A**

Analysis of the X-40A flight test data is in work. St. Louis is carrying out the aeromaneuver analysis. So far everything looks good. The data being obtained will feed in to the X-37 work.

The test crew took a week's rest after the final flight, then came back to pack up and ship the vehicle and support equipment back to Seal Beach. A couple of items borrowed from DFRC have been removed. Dummy hardware and run-out batteries will be used to replace some of the removed parts when the vehicle and FOCC go on display.

The X-40A has been returned to Seal Beach and currently is in flyable storage in Bldg. 91. It will presumably be placed on display at some time in the future.

CADS wind tunnel and flight test data agree very well.

A debriefing is being prepared by G.N.&C for the flight test program. Target date for completion is mid-August.

## **X-37**

### **Program**

With the word now out that X-37 will receive no funding from NRA8-33, the work at Boeing was cut back to about 65% of the former level. Since this is on Boeing's money, it is uncertain how long this will continue, although a period of about 2 months is rumored. Staffing has been cut back in essentially all areas.

Boeing program personnel are primarily keeping busy responding to the various programmatic options and questions generated as part of the on-going negotiations with NASA. More personnel are being reassigned to other projects.

Morale is very low at the moment. Uncertainty continues to take its toll. The possibility that some critical tasks may be allowed additional funding in order to keep the project moving and to retain vital personnel is generating some enthusiasm within the Boeing team. For improved morale everyone needs to feel that we are making progress.

More and more frequently in my discussions with Boeing lead personnel, I hear voiced the same concern that I surfaced sometime back in these reports, namely the difficulty in restarting the effort after an extended slowdown and after people have been farmed out to other projects. The corollary to that concern is the cost inherent in the delay. As has been stated previously, no one should assume that the previously planned budgets will hold in the face of a long slowdown. It is simply not possible.

I am sure that readers of these reports are weary of hearing such seemingly negative comments, however, I feel that it is vital for these words to be said, no matter how unpleasant they may be.

### **Vehicle Design**

Work presently is being concentrated on the B-52 drop test vehicle. Little or nothing is going into the orbital vehicle until something is decided as to the future of the program.

A major question that needs to be worked is: how many airframes? Originally of course there was to be only one. That led to some problems since various repairs and simple lack of experience led to the airframe being undesirably heavy. When it was hoped that additional funding would be forthcoming from SLI, two airframes were included in the program. The first airframe then became the air-launched test vehicle (ALTV). Since most space-related systems were missing from ALTV, weight was not a problem and some weight-saving options were not invoked in order to ease schedule and budget. It was assumed, probably correctly, that the second airframe would be lighter and more

suitable for orbital flight. The disappointing result of the SLI awards, however, have probably eliminated a two airframe option. There is now a degree of uncertainty within Boeing at the working level as to what the approach will be, assuming that the funding difficulty is resolved sufficiently to let the project progress. Do they proceed under the assumption that the presently existing airframe is ALTV only or that it may be called upon to do both missions?

The weight of the orbital vehicle continues to hold steady. In fact, it has gone down slightly to about 6686 lb. Potential increases at 304 to 418 lb still exceed the potential reductions at 160 lb. These numbers are based upon Shuttle requirements. Switching to an ELV should allow significant reduction in weight. The ALTV is at a comfortable 5759 lb. These data are from early in the month and may have changed slightly.

### **Flight Sciences**

This area is being particularly hard hit. The team had largely completed the low speed aerodynamics work and were concentrating on the high Mach number regime. With the decision to put all the high speed (i.e. orbital entry) work on hold, much of their current work has been halted. Personnel have been cut 75% in Flight Sciences.

The wind tunnel entry planned for this summer will go ahead but will concentrate on low speed work. If the program does in fact return to its original plan, it will probably be necessary to do another tunnel series to fill in the gaps in the high speed regime.

Work is continuing on low speed aerodynamics in support of the ALTV. The lead engineer is concerned about the rapidity with which he can restaff and get the activity ramped up when a go-ahead is received. This is a particular concern in that Flight Sciences needs to be in the lead relative to some of the other disciplines since the latter (e.g. G.N.&C) depend upon Flight Sciences for information. Delays in G.N.&C would in turn impact avionics and software.

The previously reported discrepancy in the Mach 6-10 regime is still not fully resolved. All the corrected wind tunnel data have been received from LaRC. The current slowdown has prevented any analysis being done at Boeing to resolve the discrepancy since all high speed work is on hold.

All work has stopped on RCS tasks.

### **G, N, & C**

The team is now concentrating on the B-52 drop test controls. About 3 people (out of 16 total) have been displaced due to the slowdown. These are people who are primarily involved in the orbital mission. These people will be placed on short term temporary

tasks in an effort to keep them available for a quick return when the orbital effort picks up again.

Software work in support of ALTV is moving along well. The first release is planned for mid-August.

As discussed in earlier reports, the concern regarding possible recontact with the B-52 is, probably, solved. With the body flap locked in the nose down position, the other surfaces cannot do anything that will cause the X-37 to hit the B-52. Everyone seems to accept this. The only problem is to agree upon the means to lock the body flap actuator in position. Fortunately, Range Safety seems to agree that removing power from the actuator is sufficient. They are apparently convinced that the brake will hold the actuator, and thus the flap, in place so long as there is no power. This avoids the necessity of any kind of mechanical lock. However, powering off the actuator via the control software is not acceptable. An additional switch will be required, which will be actuated a second or so after drop to allow power to the body flap actuator. This will add some weight and cost but is probably the least painful answer.

The problems with the electromechanical actuators for the control surfaces seem to be coming under control. The vendor appears to be working well. The actuators are customized to some degree to save weight as opposed to all being the same. Generally speaking the motors are all the same but with different gear boxes. The concerns about actuator heating have pretty much gone away.

## TPS

Work on the high temperature TPS has stopped, however, TPS work goes on. Since the ALTV must have the same external shape as the orbital vehicle, it is necessary to have surrogate TPS tiles, blankets, etc. to fill up the space that the real TPS would ultimately fill. This requires design work just as does the real TPS. The work is not wasted since much of the design will translate directly to the real TPS.

The ALTV will require some actual TPS in a few locations. The antennas on the ALTV will be the same as on the orbital version. Since they will have to look through the TPS on the orbital vehicle, it is necessary to have them do the same on the ALTV in order to evaluate the effect on gain, pattern, etc. For this kind of testing, a surrogate would have to approximate the real thing so closely that it is easier to use the real TPS.

The concern about the effect of the continuing delays surfaces here as well. Test slots reserved for X-37 TPS tests are being lost as their dates come and go or as the times are assigned to other programs since X-37 cannot state when they will be able to test. Similarly, agreements had been made to borrow various test fixtures in order to keep costs down. With the delays, many of these fixtures will go on to other tasks. This may

require X-37 to design and build its own fixtures. This will have schedule and cost implications.

### **Propulsion**

Main propulsion is almost entirely on hold. The lead engineer has gone to another project and at least most of the subcontractors have received at least verbal stop work orders. The remaining staff is addressing issues of termination liability. ARC, the RCS thruster provider, spent about \$250K of their IR&D on X-37 and are asking to be reimbursed for it. I suspect others will want the same.

In addition to the above, of the two people left on X-37 propulsion, one is working on Action Items from the TIM and whatever other tasks there are and the other is working on the proposal to NASA. All contracted work is stopped.

During my visit to Boeing, I picked up a rumor that NASA is looking at the possibility of going to a monopropellant hydrazine deorbit and RCS system. I assume that this arises from the irrational fear of hydrogen peroxide that pervades some parts of NASA. It was okay for John Glenn and the other Mercury astronauts to use it but somehow it has become more dangerous in the ensuing 40 years. While going to a hydrazine system is possible, people should be aware that such a change this late in the program will also have cost and schedule impact. It is also worthy of note that qualifying peroxide was one of the goals of this effort.

### **Electronics and Software**

As in the other subsystem areas most of the work not directly connected to the ALTV is slowed down or on hold.

### **Flight Operations**

A meeting was held at Boeing that included personnel from SMCTD, USAF FTC, DFRC, and others to discuss future flight operations. A major subject was the flight test approval process. There was also discussion of the flight test plan. These meetings will be quite valuable as the program moves forward since there will no doubt be a lot of pressure to make up the time lost in the slowdown.

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28 July 2001

**To:** Edgar W. Nicks  
**From:** Jim French  
**Subject:** **Monthly Report for 28 July 2001**

C: S. Turner, Lt. Col. Johannessen, M. Harris, J. Sisk, A. Nolen, T. Taylor, S. Stewart,  
Lt. Col. Kastenholz

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Note: there was no weekly report for the week ending 21 July because of vacation.

### **X-40A**

The flight test report for X-40A is still scheduled for release in mid-August. Work on it will resume after release of the software discussed below.

### **X-37**

#### **Program**

The visit of USAF generals to Boeing apparently went well. Only two showed up, Gen. Hamil apparently being unavailable. According to Boeing personnel, the visitors had a great many detail questions about the project. One topic in which there was considerable interest was whether or not two orbital flights are sufficient to obtain the desired data. The obvious answer is "No" since, with the complexity of the entry environment and the various control interactions, etc. several flights would be necessary to even begin to open the envelope. The rather arbitrary definition of four Shuttle flights as "Test Flights" with all subsequent being "Operational" was much more politically motivated than grounded in engineering. Many people consider the Shuttle still experimental.

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01 September 2001

**To:** Jay Laue  
**From:** Jim French  
**Subject:** **Monthly Report for August 2001**

C: S. Turner, Lt. Col. Johannessen, M. Harris, J. Sisk, A. Nolen, T. Taylor, S. Stewart,  
Lt. Col. Kastenholz, E. Nicks

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### **X-37**

#### **Program**

The Boeing staff is continuing to prepare briefings for USAF and Aerospace and to perform analysis to support the trade studies. They are also in the process of updating the project plan.

I have made no contact with Boeing during the latter part of the month, so most of the Boeing activity discussed below relates to activity early in the month. Most of my activity during the month focused on the Propulsion Trade Study as discussed below. Because of conflicts, I have been unable to participate in the ALTV Trade Study telecons to any great extent but have reviewed documentation as it was sent to me.

#### **G,N,&C**

The Release 2 software for the B-52 ALTV was completed and released to the software people late in July. This is software for a single string system to be used in the Simulation Lab. The software group is writing the hand-generated code that goes with the autocoded output from the G.N. & C group. The package was to be ready to pass on to the Sim Lab in mid to late August..

G.N. & C is now working on the Release 3 package which is a three-string version with substantially better sensor information.

The flight controls people are working on flexibility models to be incorporated in the code later.

Qualification testing of the SIGI guidance package was in progress early in the month. One Boeing engineer is in residence at the supplier for the duration of this activity.

### **Flight Sciences**

Nothing new to report. Continuing to wrap up the subsonic data.

### **Propulsion**

The propulsion group is looking at several options:

- The AR2-3 with hydrogen peroxide monopropellant RCS
- An all monopropellant hydrogen peroxide RCS and OMS
- An all monopropellant hydrazine RCS and OMS
- A bipropellant NTO/hydrazine engine with hydrazine monopropellant RCS

These four options are the remainder of a much larger suite of possibilities originally suggested. See below.

This activity is in support of the Propulsion Trade Study. I strongly remain an advocate of sticking with the baseline system because, I believe, it offers the maximum propulsion technology advance. The options using conventional storables will teach us nothing new in the propulsion arena. Clearly, there are arguments for the other approaches (not the least of which is cost) but I feel that the baseline should be retained if possible.

### **Propulsion Trade Studies**

There was considerable discussion of the DRM descriptions and the implications of meeting the DRM requirements. The higher orbits proposed in some of the DRMs may seriously stretch the limits of capability of the RCS / OMS thrusters in the event of main engine failure. This is probably an unlikely scenario but one that could occur. Several peroxide transfers might be required in some cases, which might not only overstress the duration capability of some thrusters but might exceed the limits of the pressurization system as defined in the requirements.

Several telecons led to refinement of the half-dozen or so proposed DRMs down to two, the first one representing a minimum orbital checkout (DRM-1) and the second



representing a mission of significant duration and delta-V that would demonstrate some of the operational potential of the vehicle and its derivatives (DRM-2).

The Trade Study was divided into two parts "Trade A" and "Trade B". The former referred to DRM-1 and the latter to DRM-2.

Significant discussion dealt with modification of the weighting factors. The final factors seemed reasonable.

Several propulsion options were developed for X-37 including the baseline, hydrogen peroxide monopropellant options, options using NTO and hydrazine and/or MMH in various arrangements and hydrazine monopropellant. The peroxide monopropellant options appear to be unable to do the more demanding DRM-2 and thus are not, in my opinion, of much interest. The conventional storable bipropellants probably offer some performance advantage over the baseline because of the relatively poor performance of the AR2-3 main engine. (Note that this advantage will largely disappear with the availability of higher performance 98% peroxide engines such as are now in development). The hydrazine monopropellant version will probably satisfy the DRMs but has no growth potential. It is basically a dead end.

A point of some mild controversy in evaluating these options is how to credit the total performance capability, i.e. what can a given system do beyond just satisfying the DRMs? This is a bit touchy since many would argue that there need be no capability beyond just meeting the most demanding DRM. However, if this and cost are the only criteria, it could easily lead us to a limited capability, dead end system. If there is to be some possibility of a future use for the X-37 OV then more capability is desirable. To this end, an evaluation criterion line item concerning maximum delta-V capability is to be included.

The number of options was steadily reduced during the series of telecons. It was temporarily decided that there was no particular point in carrying the baseline bipropellant to do DRM-1 since the monopropellant systems can do it handily. However, this decision was later reversed and a reduced propellant version of the baseline, dubbed H-1A, was included for DRM-1. To keep the number of options under control, the other options for DRM-1 were reduced to those that are capable of meeting the DRM requirements but without a huge excess of performance. Similarly, for DRM-2 the team worked to eliminate options that, by inspection, cannot meet the DRM and also those that, while they meet the requirement, are less desirable because of excess complexity or some other reason.

As a result, DRM-1 options are pretty much reduced to peroxide or hydrazine monopropellant options in addition to the reduced capacity baseline. The DRM-2 options are primarily bipropellant although the hydrazine monopropellant is an option. This points up the disparity in performance of 90% peroxide versus hydrazine as a monopropellant. The case for peroxide gets better with a higher proof but it will never be

quite as good a monopropellant as hydrazine. The various storable options involve bipropellant RCS or hydrazine monopropellant RCS. Both hydrazine and MMH were originally considered for the MPS. However the choice was made to use options that used NTO and hydrazine in the MPS and monopropellant hydrazine thrusters for RCS as the simplest approach.

The chosen options were refined to support the propulsion trade studies. As of this report, we are carrying three options for each DRM. In both cases, the peroxide baseline (using the AR2-3) is included, referred to as H-1 A for DRM-1, B for DRM-2, is included. For DRM-1 the other two are H-3A: a multiple RCS tank  $H_2O_2$  system and S-3A: a single tank  $N_2H_4$  system. For DRM-2, the other two are S-2B: an  $N_2H_4$ /NTO bipropellant system with  $N_2H_4$  monopropellant RCS and S-3B: a multiple tank  $N_2H_4$  monopropellant system.

Boeing has done estimates of the weight reductions inherent in each option relative to the baseline H-1. These estimates are -663 lb for H-3A, -729 lb for S-3A, -478 lb for S-3B, and -559 for S-2B. Recall that these numbers are very preliminary. It is also well to remember that these are not equal performers but for most, simply meet the DRM requirements.

MSFC has assembled a very good preliminary list showing a subsystem testing approach. While obviously more depth is needed this is a good start. It brings up the issue that facility (or at least non-flight) tanks may be substituted for flight tanks in many cases. The general feeling seems to be that this option applies mostly to the non-peroxide options, an assumption that may justify a second look.

A significant point of discussion is the need for fidelity in ground test systems to support development of the various propulsion system types. This function is supported in the baseline by the planned brassboard. It is suggested by the list discussed above and in other discussions that some of the options need a less elaborate system. This may well be true but we must be careful not to favor the newer system concepts by over optimism.

### **Preliminary Results of Trade Studies**

I question why Material Compatibility is rated so poorly for the peroxide options. There is an extensive database on such issues. Admittedly, some of the data are not as modern as that for hydrazine but there is still significant information. This makes it sound as if there was none.

While the gauging accuracy and reliability for peroxide is probably inferior to that for the other propellants, is it really as bad as indicated?

What is the basis for the assumption that all peroxide systems need active pressure control while the others use regulators? True, the Baseline is designed that way and it

may be justified for the complex propellant transfers and such (although I can see a way to do it with on/off valves and regulators) but I'm not sure it holds true for H-3A.

H-1 and S-2B are stated to require the same turnaround time but H-1 is construed as less desirable. Why? Better justification is needed.

I have some difficulty seeing the large plume of the AR2-3 as being a significant factor. It seems to me that the main worry about plume impingement will come from the RCS thrusters and, in that case, peroxide is more benign.

### **Trade Study Thoughts**

This is largely a subjective opinion but I do not see H-3A and S-3B being greatly superior in terms of schedule, particularly H-3A.

I question H-1 being substantially lower than H-3A in terms of development risk. The AR2-3 seems relatively low risk at this point. Concerns about peroxide transfer from main to RCS tanks are valid and this may reduce the desirability of H-1.

I think the traceability of S-3A and S-3B is very low. No operational vehicle is likely to use either scheme so what is being traced to what? I do not feel that H-3A is very high by the same logic but it does advance peroxide technology so some credit for that is probably valid. S-2B at least has the virtue that such a system could be used in an operational system if the decision goes against peroxide.

### **Cost Saving**

I have reviewed the cost saving document generated as part of the trade study and find no problem with the items listed. I assume Boeing has done enough homework to validate the numbers.

### **Propulsion Concept Evaluation**

In addition to the Propulsion Trade Study telecons, I was asked to review a set of documents (Opening Remarks, Popp Status Expanded, and Risk Factors 6-4-01) regarding the concerns of the MSFC propulsion community regarding the use of the hydrogen peroxide / JP propellant combination in the X-37. I was asked to comment on these documents partly as a result of my strong support of continuing with the baseline system as opposed to the proposed development of systems using conventional storables. In summary, my response is that I have no major disagreement with the concerns raised by MSFC propulsion. There is serious work to be done. Much of the work about which they express concern would also have to be done with the proposed replacement systems

and much that has already been done on the baseline would have to be repeated if we switched to another approach. Any saving of money or schedule is doubtful at best. More to the point, however, and this has been my real point of contention all along, the program was originally proposed with the idea of bringing peroxide / JP technology up to speed in order to offer a non-toxic, non-carcinogenic alternative to current storables. If we drop this aspect of the program, we lose a major technology contribution and, incidentally, one in which the USAF has substantial interest. NASA is supposed to be in the business of advancing technology, not doing things we already know how to do.

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15 September 2001

**To:** Edgar W. Nicks  
**From:** Jim French  
**Subject:** **Weekly Report for 15 September 2001**

C: S. Turner, Lt. Col. Johannessen, M. Harris, J. Sisk, A. Nolen, T. Taylor, S. Stewart,  
Lt. Col. Kastenholtz

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### **X-37**

#### **Program**

With the Air Force decision not to participate in the X-37 program and with no launch vehicle being apparently available, there is very little to do pending a decision as to whether the X-37 program will go forward and, if so, in what form.

Because of the uncertainty of the situation, I have had no contact with Boeing for several weeks. This week I decided to make a few telephone contacts simply to sample the situation and to maintain such contacts as remain. It appears that, as of today, Boeing is cutting back to an approximate 50 person level. This is apparently based upon the assumption that whatever continuation program is developed will be at that level.

Apparently the GN&C and software groups are being retained at about their current level but most other areas are being sharply reduced. Flight Sciences will be reduced to one person. This reflects the fact that most of the subsonic aero is done and there is unlikely to be any immediate need for higher speed data. While the propulsion personnel have received no official word at this point, they read the signs as indicating that there will be no propulsion whatever on the vehicle in the new program and are anticipating that they will move on.

There were no telecons or other activities regarding the trade studies. It seems likely that, given present circumstances, the trade studies are no longer of interest and will not continue.

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<b>13. ABSTRACT (Maximum 200 Words)</b> The X-37 vehicle is a technology demonstrator sponsored by NASA. It includes a number of experiments both imbedded (i.e., essential aspects of the vehicle) and separate. The technologies demonstrated will be useful in future operational versions as well as having broad applications to other programs. Mr. James R. French, of JRF Engineering Services and as a consultant to SAIC, has provided technical support to the X-37 NASA Program Office since the beginning of the program. In providing this service, Mr. French has maintained close contact with the Boeing Seal Beach and Rocketdyne technical teams via telephone, e-mail, and periodic visits. His interfaces were primarily with the working engineers in order to provide NASA sponsors with a different view than that achieved through management channels. Mr. French's periodic and highly detailed technical reports were submitted to NASA and SAIC on a weekly/monthly basis. These reports addressed a wide spectrum of programmatic and technical interests related to the X-37 Program including vehicle design, flight sciences, propulsion, thermal protection, Guidance Navigation & Control (GN&C), structures, and operations. This deliverable is presented as a consolidation of the twelve monthly reports submitted during the Contract's Option Year 2.				
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